FOCUS ON EARTH SCIENCE

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PREFACE

Focus on Earth Science is a study of the planet earth—its features, its forces, its place in the solar system, and its place in the universe. The study proceeds from an overview of the characteristics of the earth, through an in-depth study of its matter and processes, to a survey of matter and processes in the universe. This presentation examines and explains concepts in a vocabulary suited to the language sophistication of the student.

This approach to earth science was developed to cultivate an observing eye and an inquiring mind through a carefully planned sequence of learning. Each of the twenty-three chapters demonstrates the importance of observation and experimentation in the development of scientific principles. Organization of the areas encourages the student to apply his newly acquired skill and insight to an interpretation of the never-ending changes of his environment.

The scope of the text leads from familiar experiences and observations to an understanding of abstract concepts such as geologic time, astronomical distances, and inferences about celestial bodies. Basic principles of chemistry and physics are introduced early to form the framework for understanding the changes that occur in minerals, rocks, and celestial bodies. Within the six units, the materials and processes of the earth and the universe are explained in terms of matter and energy.

Focus on Earth Science is a suitable introduction to interpretation of the matter and processes of the earth. Complex ideas are presented simply and then developed. Scientific principles are reinforced immediately by experiments and activities which are placed appropriately within the text. The student repeatedly uses his experiences in observation, data gathering, and cause and effect relationships to interpret his environment. Experiments and activities have been devised to use inexpensive materials that are readily available. Each laboratory segment is effective without being either overwhelming or time-consuming.

Throughout the text memorization is minimized and problem-solving is emphasized. Theories and hypotheses to explain natural phenomena are presented from the historical viewpoint. It is this aspect which acquaints the student with the scientific endeavors of past investigators and fosters his appreciation of scientific observation.

Self-study aids are incorporated in the text. Each chapter contains a summary of main ideas as well as a variety of questions designed to help the student recall factual material and to encourage his independent thinking. Important concepts printed in the margins of each page are useful for reference and review. Photographs, tables, and drawings have been selected carefully to help the student visualize the ideas presented in the accompanying text and to assist him to read with understanding. New terms associated with the scientific presentation of earth study are defined and spelled phonetically in the text and in an accompanying glossary. Appendices and an extensive index are included.

During the writing of *Focus on Earth Science*, the authors have had many helpful suggestions from students, teachers, and colleagues. To them, as well as to the editors and reviewers who have contributed to the accuracy and usefulness of the text, the authors offer their thanks.

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Origin and Motions of the Earth

In 1571, a Danish scientist and teacher named Peter Severinus gave his students the following advice: "Go my sons, sell your lands, your houses, your garments, and your jewelry; burn your books. On the other hand buy yourselves stout shoes, get away to the mountains, search the valleys, the deserts, the shores of the seas, and the deepest recesses of the world; mark well the distinctions between animals, the differences among plants, the various kinds of minerals, the properties and modes of origin of everything that exists. Be not ashamed to learn by heart the astronomy and terrestrial philosophy of the peasantry. Lastly purchase coals, build furnaces, watch and experiment without wearying. In this way and no other will you arrive at a knowledge of things and their properties."

What did Severinus really expect of his students? Did he intend that they burn their books and abandon their homes? Probably not. Instead he was encouraging them to learn about their environment through observation and experimentation. He did not want his students to accept myths and superstitions as explanations of natural events.

1:1 *Earth Science*

Learning associated with the out-of-doors was a new idea. Before Severinus' time, education stressed reading, writing, and discussion, but included very little experimentation and observation of nature. Since the sixteenth century, however, investigations and measurements of the environment have become an important part of learning.

Terrestrial means of the earth; **philosophy** is the science which investigates facts and principles underlying all knowledge and being.

Recall that Severinus wanted his students to learn the terrestrial philosophy (te res′tree ul · fi lahs′a fee) * of the peasantry.

*See Pronunciation Key, p. 510.

His point was that peasants observed the forces of nature every day; they planted their crops and reaped their harvests according to nature's cycles. Their observations would be correct, even though their explanations might be imaginative. Severinus wanted his students to have firsthand knowledge of "things" and their properties. He wanted them to observe nature just as the peasants did.

Modern geologists and earth scientists benefit from the observations and experiments of earlier scientists. But they still search the mountains and the valleys, the deserts and the oceans to learn more about nature. They continue to discover new facts based upon actual observations and measurements.

Earth science is the study of the planet earth—its land masses, its seas, and its atmosphere. It is not a new science; men have always been curious about their surroundings. Ancient men tried to explain their environment by myths, legends, and tales. Modern men study their surroundings in an attempt to

Robert F. Moseley, Jr.

Figure 1-1. Man's curiosity about earth, sea, and air has led him to probe his environment and revise his old ideas in light of his new findings.

Knowledge of the earth comes through observation and experimentation.

understand the laws of nature that govern their environment. However, the environment is so complete that no one scientist can fully study all of its parts. Some fields of investigation related to the study of the earth are: *lithology* (lith ahl'a jee), the study of rocks; *structure*, the study of the forces that have shaped the planet; *historical geology*, the study of changes that have occurred on the planet earth since its beginning; *meteorology* (meet ee a rahl'a jee), the study of the atmosphere; *oceanography*, the study of the earth's seas and their influence on the land masses.

Chemistry is the science concerned with the composition of matter. **Physics** is the science concerned with facts about matter and motion. **Biology** is the study of living matter in all its forms. **Astronomy** is the science of the celestial bodies, their motions, distances, positions, and magnitudes. **Geologic history** is the study of the development of earth.

Earth science deals with changes in the materials of the earth and the causes of such changes. It depends upon both chemistry and physics for an understanding of these materials. Earth science depends upon biology for an understanding of life processes, and upon geologic history for a recounting of the changes in both plants and animals. Modern earth science also includes those areas of astronomy that concern the earth and its relationship to the universe.

Have you ever wondered why volcanoes erupt, why glaciers creep across the land, why oceans build some shores but wear down others, why rivers flood certain lands and cut canyons elsewhere? Earth science is a study of the causes and effects of such events.

1:2 *Origin of the Earth*

No one knows how the earth began. Although many facts about the origin of the earth have been learned, much remains unknown. A number of *hypotheses* (hie pahth'e seez') have been suggested to explain the known facts. A **hypothesis** (hie pahth'e sis) is a proposed solution for a problem and is based on available information. A hypothesis is often called an *educated guess* because it has not been proved. As more facts are learned, some hypotheses are discarded because they do not fit the new information. Modern explanations of the origin of the earth are called *theories* (thee'a rees) instead of hypotheses. A **scientific theory** is a general principle offered to explain many related facts and events. A theory is based on more reliable information than is a hypothesis.

Ancient men tried to explain the trembling of the earth. Some thought it was due to movements of a great giant who supported

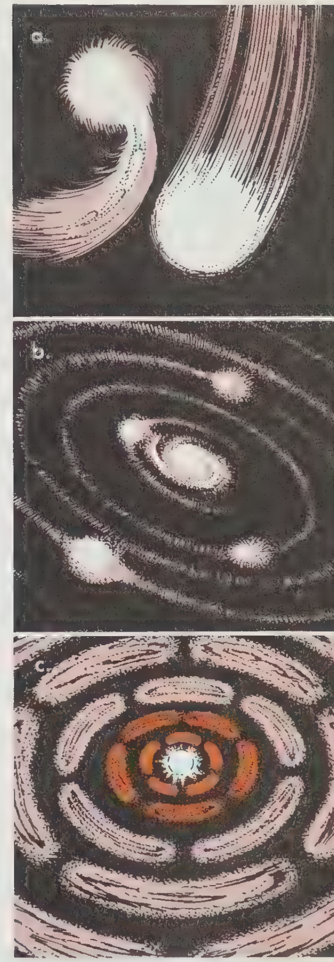


Figure 1-2. Theories of solar system origin: a. near collision, b. nebular, c. dust cloud. All theories of solar system origin must account for the observed distribution of angular momentum.

the earth on his toe. Occasionally the giant tired of holding the earth in a rigid position. When his muscles relaxed, the earth shook and trembled, causing an earthquake. No one questions that earthquakes occur. This is a fact, however the cause of an earthquake is no longer explained by the old "giant hypothesis." Scientists have proved that rocks crack and move upward, downward, or sideward. Movements of rocks within the earth cause earthquake tremors (trem′ers). The "giant hypothesis" is just one example of the way in which hypotheses change. Discovery of new facts often shows that old hypotheses are not true. For example, explanations of the origin of the earth have undergone many changes as astronomers learned more and more about the universe.

One of the earliest of the modern hypotheses for the origin of the earth was proposed by George de Buffon in 1749. This French naturalist thought that a comet had come close to the sun and pulled away some of the sun's matter. Buffon supposed that the planets were formed from the sun's matter. Few scientists have taken Buffon's idea seriously. But his suggestion was the forerunner of the **near-collision hypothesis** proposed at the beginning of this century by two American scientists, T. C. Chamberlin and F. R. Moulton. Their hypothesis was accepted as sound until the early 1940's. Chamberlin and Moulton believed that a second star had nearly collided with the star called the sun. During the near-collision, particles of the sun's matter were pulled away. These particles, called **planetesimals** (plan e tes′i mals), revolved around the sun, held there by the sun's gravitational attraction for the planetesimals. Gradually, the planetesimals collected and formed larger and larger masses which became the planets.

Planetesimal hypothesis suggested that planets were formed from particles of matter from the sun.

An entirely different hypothesis for the origin of the solar system was suggested by Immanuel Kant, a German philosopher, in 1755. Kant's idea was expanded later by Pierre de Laplace, a French mathematician. The Kant-Laplace hypothesis is similar in many respects to today's most accepted concept of the origin of the solar system. Kant and Laplace pictured a large cloud of hot gas rotating in space. Gradually, the gas cooled and contracted. Some rings of gas were left behind as the main mass condensed and formed the sun. These gas rings were thrown

outward by centrifugal force of the whirling mass of gas as it contracted. Each separate ring supposedly condensed into a planet. But hot gases do not tend to condense. Instead, hot gases expand into space. In spite of its weaknesses, the Kant-Laplace hypothesis was an important step forward in the understanding of the universe. It was known as the **nebular** (neb′ye ler) **hypothesis** because it suggested that large clouds of gas called *nebulae* (neb′ye lee) existed in outer space.

Planet means wanderer; all celestial bodies move, but stars are so far away that they appear static.

Carl von Weizsacker, a German physicist, suggested the basic ideas of the modern **dust cloud theory** in 1943. Astrono-

Mount Wilson and Palomar Observatories

Figure 1-3. These four nebulae in the constellation Leo are about 20 million light years away.

mers have found that clouds of gas and dust do exist in outer space. But the gaseous material is cold, not hot, as Kant thought it was. Weizsacker's theory explains why all of the planets in the solar system would revolve in the same direction, why they would have nearly circular orbits, and why all of them would orbit in nearly the same plane.

Modern theories, based on ideas of Weizsacker and Kuiper, suggest that: (1) a combination of cool gas and dust formed the planets, (2) planets formed from eddies in the nebula, (3) center of the nebula became the sun and, because of nuclear reactions, began to radiate energy.

Gerard Kuiper, an American astronomer, expanded Weizsacker's theory in 1951. Both Kuiper and Weizsacker deserve credit for the modern theories of the origin of the solar system. Today most scientists believe that the solar system developed from a large mass of rotating gas and dust. At first the rate of rotation was slow, but gradually the rate grew faster and faster. Particles within the dust cloud bumped into one another more and more often as the rate of rotation increased. Many of the particles clung together because of their gravitational attraction for each other. Small clumps or knots of matter developed in this way. These clumps gradually increased in size as they attracted more and more particles. Eventually, the solar system developed from these masses of matter.

Astronomers believe that, early in the history of the nebula, the cloud flattened into the shape of a disk. During this stage, matter in the nebula began to rotate in the same plane and in approximately the same direction. *Eddies* (ed′ees), or whirlpools, like the circular currents within a swiftly moving river, began to separate the nebula into parts. Each part became a clump of matter as the particles were swept closer and closer together. Eventually each major eddy became a planet, rotating around its own center and carrying itself forward around the center of the dust cloud.

Gas at the center of the nebula condensed into the largest mass of the solar system. Its particles of matter came into contact so often that the temperature of the mass began to increase. As the temperature rose higher and higher due to the collision of particles, changes similar to those within a nuclear bomb occurred. The mass began to radiate energy in the form of heat and light. Thus, the star called the *sun* was born. But remember, all of these theories are based on the best information available today and all are subject to change in light of any new scientific information.

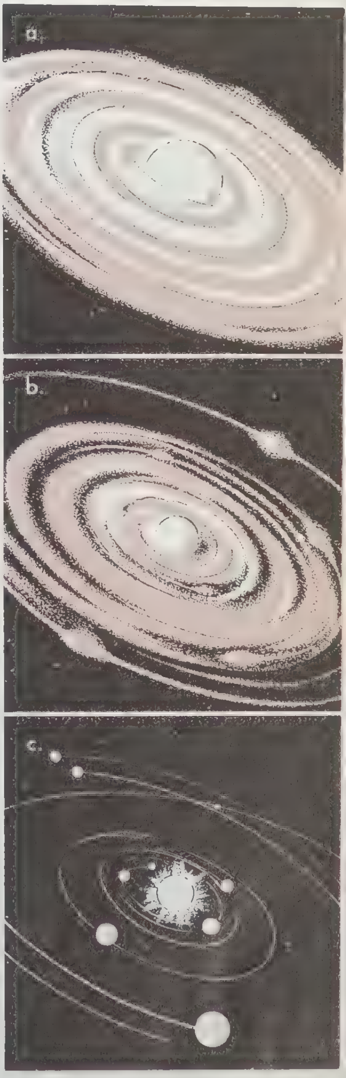


Figure 1-4. Matter within large eddies is believed to have condensed to form the planets which are spaced within the solar system in a mathematical relationship known as Bode's law.


Figure 1-5.

EXPERIMENT. Compare the movement of particles on water with the presumed movements in the solar system's nebula. Place two egg beaters in a shallow bowl. Add water to the bowl to cover the webs of the beaters. Gently and evenly distribute some pencil shavings onto the water. Start one beater in the center of the bowl. Stir slowly and then gradually increase the speed. Notice which shavings move first. Where do they move? What force causes the movement? Do all of the shavings move at the same rate? Does the size of a shaving have any effect on its movement? Stop the beater and observe which shavings stop moving first.

Resume the beating in the center of the bowl. Have a friend start the second egg beater rotating slowly near the outer edge of the bowl. How are the shavings affected by this second center of movement? Alternate the speeds of both beaters and record the results. How is the movement of the shavings affected?

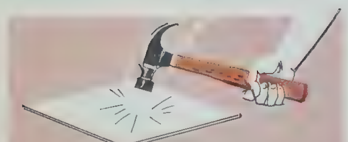


Figure 1-6.

EXPERIMENT. Test the relationship between collision and temperature. Hammer on a piece of sheet metal for several minutes. Feel the sheet metal. What has happened to its temperature? Explain the change.

1:3 Gravity

Aristotle (384-322 B.C.), a Greek philosopher, suggested that a heavy body (large mass) falls faster than a light-weight body (small mass). Aristotle's theory was generally accepted until early in the seventeenth century. Then an Italian astronomer and physicist named Galileo demonstrated that the increasing speed, or **acceleration** (ik sel a rae′shun), of a falling object does not depend upon its mass. A falling body near the surface of the earth has an acceleration of 32 feet (980 centimeters*) per second per second in a vacuum. This means that the **velocity** (ve lahs′et ee) of the body increases 32 ft (980 cm) per second for every second that it falls. In other words, the farther an object falls, the faster it falls. Bodies that fall in air do not fall as fast as bodies in a vacuum. Friction between the body and air decreases its speed slightly. For most problems, an acceleration of 32 ft/sec/sec is exact enough. (Figure 1–7.)

Vacuum is an area in which there is little matter present.

Acceleration is the rate at which velocity increases in a unit of time. **Velocity** is the distance traveled in a unit of time. **Mass** is the quantity of matter present in a body.

* See Appendix A, p. 506.

Galileo's experiments did not explain why bodies fall or why they fall at a rate independent of their mass. But his efforts laid the groundwork for the explanation of gravity developed by the English scientist Sir Isaac Newton.

In 1680, Newton explained the relationships that exist between all *observable* bodies. His explanations are called the *laws of motion*; they are the basic ideas of physics. Study of outer space has contributed some new ideas to physics, but Newton's ideas still explain the motions of observable bodies.

Newton concluded that all bodies at rest resist motion, but if a body is set in motion by some outside force, it tends to continue to move in a straight line. This property of matter is called **inertia** (in er′shuh). Some force must be applied to make a body move, to change the direction of its motion, or to stop it.

Bodies may be observed falling to earth. Planetary bodies may be observed moving through the sky. Newton's laws of motion explain both motions in terms of gravitational attraction.

All particles or objects attract all other particles or objects. This mutual attraction between all matter is known as **gravitation** (grav i tae′shun). The force of gravitation that pulls bodies toward one another is proportional to the product of the mass of the bodies divided by the square of the distance between them. This relationship is known as Newton's **law of gravitation.** It may be written mathematically as follows:

$$F :: \frac{M \times m}{d^2}.$$

In this equation, F represents the gravitational force or attraction, : : represents "is proportional to," M represents the mass of one body or object, m represents the mass of the second body or object, and d represents the distance between the centers of the two bodies or objects.

Gravitational attraction between small bodies, such as oranges, apples, and even automobiles, is not measurable by ordinary methods. However, objects of large mass have an extremely large gravitational attraction. For example, the gravitational attraction between earth and moon is several trillion tons. Gravitational attraction of the earth for objects near its surface is called *gravity*. A measure of this gravitational pull of the earth on bodies near its surface is called *weight*.

Figure 1-7. In a vacuum, would a feather and a steel ball fall with the same acceleration?

PROBLEM

If you were standing on top of Mt. Everest (elevation about 29,000 ft above sea level), would the gravitational attraction between you and the earth be greater or less than it would be at sea level? Why?

Newton's laws led to the discovery of unknown planets, an explanation of ocean tides, a prediction of the true shape of the earth, and a reason for the slow change in the direction of the axis on which the earth turns. Newton explained the *how* of movements of all observable bodies, including the bodies of the solar system.

1:4 Motions of the Earth

Movements of bodies in space are determined by the gravitational attraction of one body for another. Bodies of small mass tend to move toward bodies of greater mass. The sun has the greatest mass of all the bodies in the solar system. For example, the mass of the sun is 333,500 times the mass of the earth. Therefore, the earth tends to move toward the sun. In fact, each planet is pulled inward toward the sun which is at the center of the solar system. If there were no gravitational attraction of the sun, inertia of the planets would tend to keep them moving in a straight line. The gravitational attraction of the sun exerts a force on the planet. The resultant of the two forces, which is the difference between the planet's inertia and the gravitational force, causes the planets to follow a curved path. Because the planets do not move at uniform speeds, their paths are *elliptical* (e lip′ti kal). (Figure 1-8.) As viewed from the North Star, the motion of the planets is

Elliptical orbit is the path of a point that moves so the sum of its distance from two fixed points (foci) is constant.

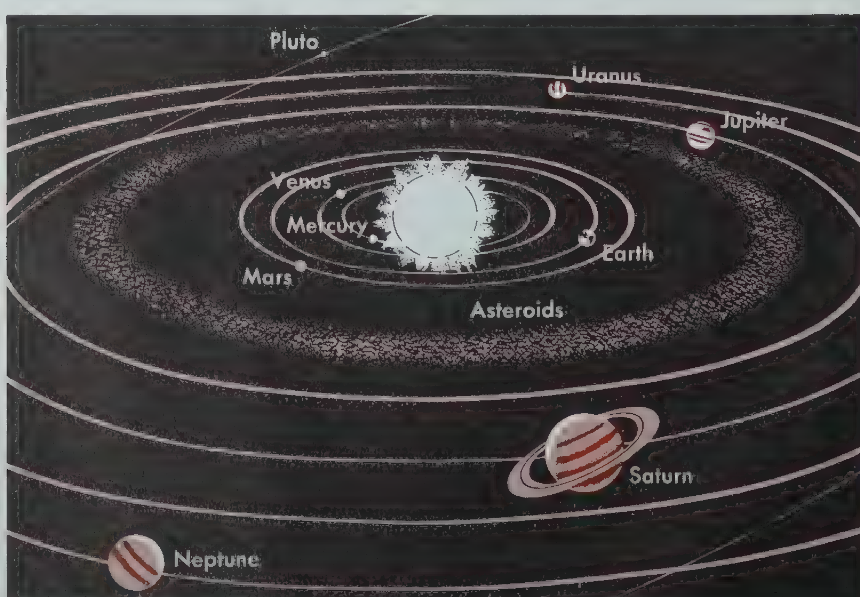


Figure 1-8. The gravitational attraction of the sun controls several thousand independent bodies. But the volume of space occupied by the solar system is so vast that it may be considered nearly empty.

in a counterclockwise direction, approximately in the plane of the sun's equator. The plane in which a planet orbits the sun is called the *plane of the ecliptic* (i klip'tik).

Plane of the ecliptic is the flat surface that has no edge or boundary which results from the extension of the orbit of the earth into space.

EXPERIMENT. Hold a ball in your hand, then let it drop without giving it a push. What force causes the ball to fall? Throw the ball horizontally. What happens to the ball? What kind of path does the ball follow? What forces determine the path of the ball?

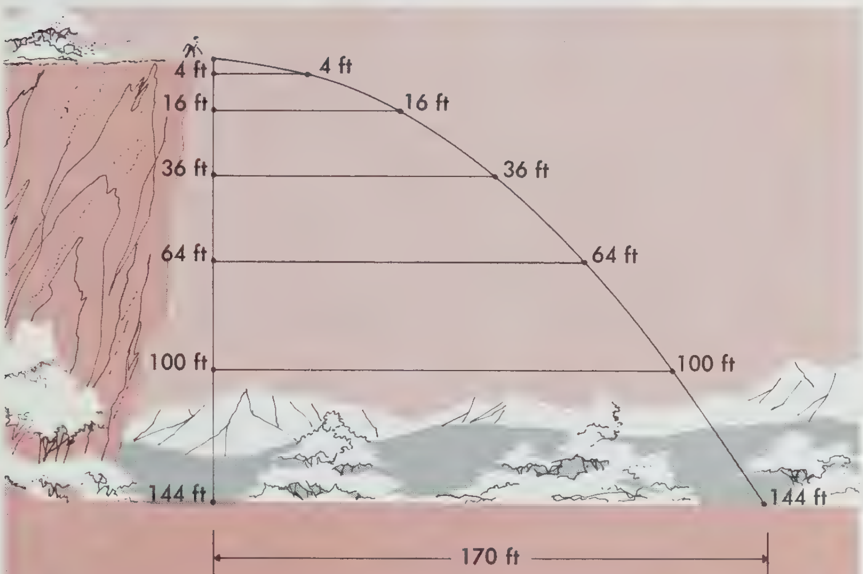


Figure 1-9.

Figure 1–9 illustrates the combined effect of gravity and horizontal movement. Two balls are released simultaneously from an overhanging cliff 144 ft high. One ball is allowed to fall freely. The other ball is thrown horizontally from the cliff. As shown in the diagram, the positions of the two balls are photographed every one-half second. Compare the vertical fall of one ball with that of the other ball. (This rate of fall is indicated in feet per every one-half second.) How far does each ball fall in 3 sec? What force determines the vertical movement? What forces determine the horizontal movement of the second ball? Is the path followed by the second ball circular or is it a parabola? The combination of forces illustrated is the same as the forces acting on the planets. What was the direction of forces that determined the planets' orbits? What were the forces?

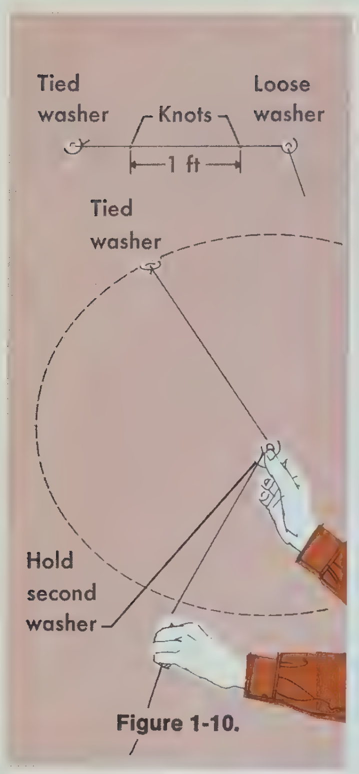


Figure 1-10.

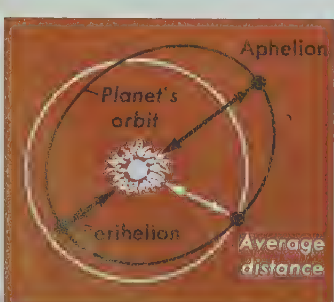
EXPERIMENT. Tie knots about 1 ft apart in a string at least 4 ft long. Tie a heavy iron washer at one end of the string and thread the loose end through another washer. Do not tie the second washer to the string. Hold the free end of the string in one hand and the loose washer in the other hand. (Figure 1–10.) Swing the tied washer in a circle over your head. Be sure you do not hit anyone. *Increase the speed of the moving washer until the string is taut. Now gradually shorten the string, one section at a time, by pulling it down through the washer in your hand. Continue to rotate the tied washer. To keep the string taut, do you need to increase or decrease the speed of the swinging washer?*

Replace the large washer at the end of the string with a small washer and repeat the first part of the experiment. Does the size of the washer affect the speed necessary to keep the string taut? Compare the materials used in your experiment to the parts of the solar system. What does the washer in your hand represent? What do the string and the tied washer represent? How is the size of a planet and its distance from the sun related to this experiment? What effects do a planet's mass and its distance from the sun have on its velocity?

Problem

1. If all of the planets were the same size, but were different distances from the sun, which ones would move fastest around the sun?
2. If all of the planets were their actual sizes, but were the same distance from the sun, which ones would move fastest around the sun?
3. Why is the sun at the center of the solar system?

Figure 1-11. Solar system distances can be expressed in miles, kilometers, astronomical units, or light-hours.



Two familiar motions of the earth are *revolution* and *rotation.* **Revolution** (rev a loo′shun) is the movement of the earth around the sun; **rotation** (roh tae′shun) is the spinning motion of the earth on its axis. The earth revolves around the sun in a path called an *orbit.* The shape of the orbit is elliptical. The distance between earth and sun depends upon the position of the earth in the ellipse. (Figure 1–11.) In January, the earth is nearest the sun. This point in the ellipse is called **perihelion** (per i heel′yan). At perihelion, the earth is 91.5 million mi away from the sun and is moving more rapidly than when it is farther from the sun. In July, the distance between the earth and the sun is 94.5 million mi. This point in the orbit is called

aphelion (a feel′yan). At aphelion, the earth is farthest from the sun. The mean or average distance between the earth and the sun is 93 million mi. This mean distance is called one *astronomical unit.* It is often used to express distances within the solar system. For example, the mean distance between Mars and the sun is 1.524 astronomical units (142 million mi).

Mean or average distance between earth and sun is 93 million mi **(one astronomical unit).**

One *earth year* is the period of time required for the earth to make one revolution around the sun. If the starting point in the orbit is determined by sighting on a star, the orbital period is called the *sidereal* (sie dir′ee al) *year*, or the *star year.* If the starting point is measured in relation to the position of the sun, the orbital period is called the *solar year*, or the *tropical year.* The tropical year is the basis for our calendars. One complete tropical year requires approximately 365¼ days.

Once every 24 hours, the earth rotates or turns on its axis, if the starting point is measured in relation to the sun. The day is slightly shorter if the period of rotation is measured in relation to a star; this is the *sidereal day.* The axis on which the earth rotates is tilted in relation to its plane of orbit. The angle of tilt, or *inclination,* is 23½° measured from a perpendicular to the plane of the earth's orbit. It is 66½° measured from the axis to the orbital plane. (Figure 1–12.) The tilt of the axis is the cause of the difference in the length of daylight in winter and summer. In the northern hemisphere, there are more than 12 hours of daylight from about March 21 to September 23 (spring and summer) and fewer than 12 hours of daylight from about September 23 to March 21 (fall and winter). The southern hemisphere has more than 12 hours of daylight from about September 21 through March 23 (spring and summer) and fewer than 12 hours of daylight from about March 21 to September 23 (fall and winter). The seasons are opposite in the

Time periods measured by sighting on a star **(sidereal time)** are shorter than those measured by sighting on the sun or moon.

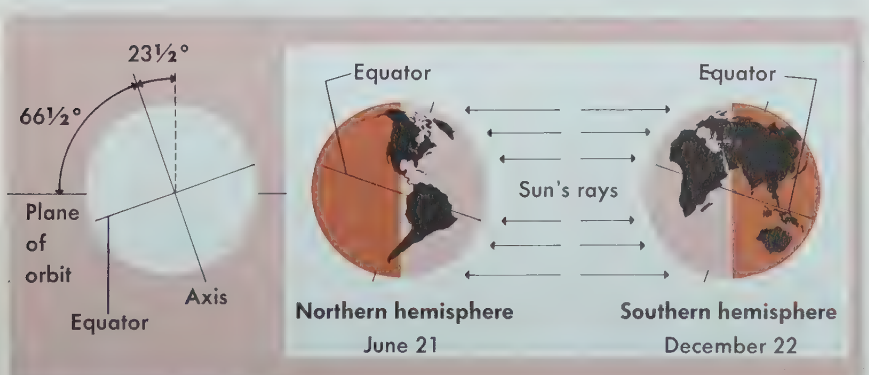


Figure 1-12. Earth's axis maintains its 23½° inclination from the vertical to its plane of orbit and points at all times to the north celestial pole.

two hemispheres because of the position of the sun in relation to the axis of the earth.

Earth has a natural *satellite* (sat′el iet), or moon, which makes one revolution around the earth in 29½ days measured from new moon to new moon. This orbital period takes slightly over 2 days longer than the *sideral orbit* which is measured in relation to a star. The *month* is a unit of time corresponding nearly to the orbit of the moon around the earth.

Eclipse or darkening of either earth or moon may occur if one or the other body lies in direct line with the sun and cuts off the sun's light.

The orbital plane of the moon is inclined approximately 5° from the ecliptic plane of the earth. Therefore, the moon and the earth seldom lie between one another and the sun. When the two bodies are in a direct line with the sun, an *eclipse* (i klips′) occurs. A *lunar eclipse* occurs when the earth is directly between the moon and the sun. Then the shadow of the earth falls across the moon and darkens it. A *solar eclipse* occurs when the moon is directly between the earth and the sun. Then the shadow of the moon falls on the surface of the earth, and areas of the earth are darkened. It is called a solar eclipse because, in the darkened areas, part or all of the sun is obscured by the moon's disk.

Earth and its moon are so close together that they form an earth-moon system. The earth and its moon are 238,857 mi apart. But this mean distance is actually very small when compared to the 93 million mi between the earth and the sun. The earth-moon system revolves around the sun. The center of grav-


NASA

Figure 1-13. This eclipse of the sun was viewed from a spacecraft during its pass over South America.

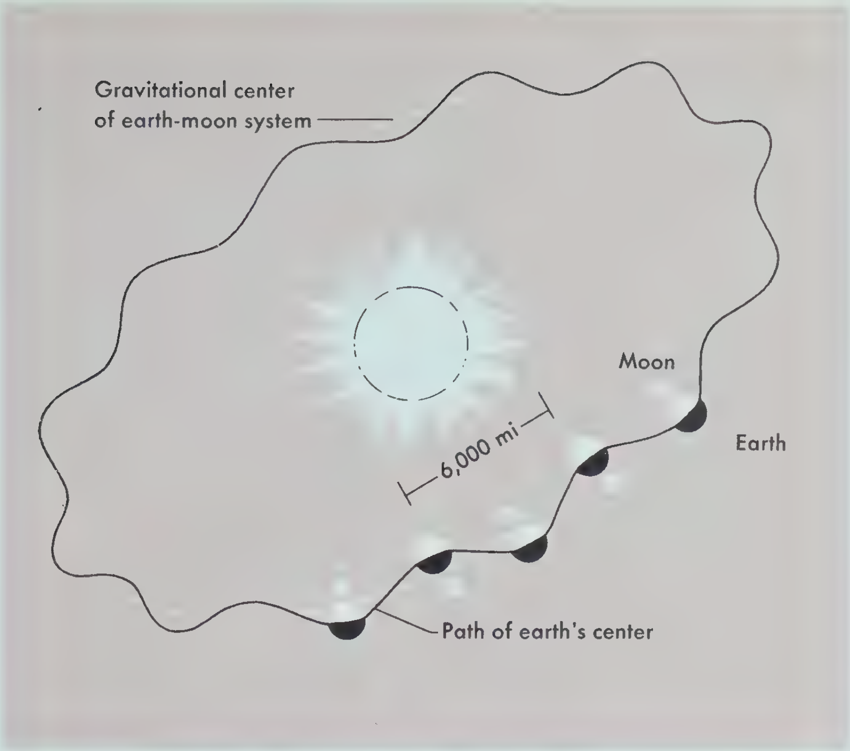
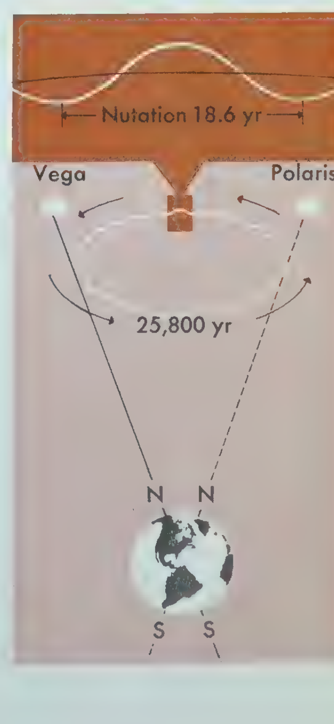


Figure 1-14. Center of gravity for the earth-moon system traces a smooth ellipse during its yearly orbit around the sun, but the center of the moon and center of the earth have an intertwined path as the moon orbits the earth.

ity for the system does not lie at the true center of the earth. Instead, the gravitational center of the earth-moon system is approximately 1,000 mi below the earth's surface or 3,000 mi from the true center of the earth. Thus, the center of gravity for the earth-moon system is 3,000 mi closer to the moon than the true center of the earth is.

Several motions result from the earth-moon relationship. The gravitational center of the earth-moon system traces a smooth ellipse around the sun. The center of the earth traces an S-shaped curve along the ellipse. The range of this S-curve movement is approximately 6,000 mi. (Figure 1–14.) As the moon alternately passes north and then south of the earth, it causes an imbalance in the rotation of the earth. Once every 18.6 years, the moon changes its position with respect to the earth and sun. (Figure 1–15.) This movement is known as **nutation** (neu tae'shun). **Precession** (pree sesh'un) refers to the motion of the earth's axis as it traces a cone-shaped pattern during a 25,800-year cycle. (Table 1—1.) The north pole of the earth now points to the star Polaris. Thus, *Polaris* is called the North Star. In approximately 12,900 years, the north pole of the earth will have changed its position and will point toward the star *Vega* (vee'ga). Then Vega will be called the North Star.

Figure 1-15. At present, earth's axis is 1° from Polaris; in 2100, it will be only ½° away, its closest position to Polaris.



Nutation and precession are irregularities in the path traced by the earth's axis.

In another movement through space, the earth and the sun move in an orbit through the Milky Way Galaxy. This journey requires 200 million years. During this cycle, the solar system rushes onward in space at a rate of 150 mi/sec!

Table 1–1. *Motions of the Earth*

Mean distance from sun	93,000,000 mi (1 astronomical unit)
Mean distance from moon	238,857 mi
Sidereal year (measured from star position)	$365^d\ 6^h\ 9^m\ 9^s$*
Tropical year (measured from equinox**)	$365^d\ 5^h\ 48^m$
Sidereal day	$23^h\ 56^m\ 4^s$
Solar day	24^h
Inclination of axis from perpendicular to plane of orbit	23½°
Orbital velocity	18.5 mi/sec
Precessional cycle***	$25{,}800^y$

* y=year, d=day, h=hour, m=minute, s=second

** Equinox—the two points at which the plane of the ecliptic cuts the *celestial equator*. (Section 21:3.) Spring begins when the sun passes the vernal equinox (about March 21). Fall begins when the sun passes the autumnal equinox (about September 22). During the equinoxes, day and night are equal.

*** Precession—often referred to as "precession of the equinoxes." Because the earth's axis is moving in space, the intersection of the ecliptic and the celestial equator is gradually moving westward.

MAIN IDEAS

1. A study of earth science requires observation and investigation of earth processes and earth materials. Earth science depends upon many other fields of science.
2. Hypotheses change with the discovery of new facts that add to the understanding of natural processes.
3. Scientific theories explain many related facts and are based on more evidence than hypotheses are.
4. Early hypotheses about the earth's origin suggested that the planets were formed from the sun's matter. The matter was either pulled off by a passing star or left behind during the condensation of hot gases.

5. According to Weizsacker and Kuiper, all members of the solar system came from the same original nebula which consisted of cool gas and dust.

6. An experiment by Galileo led to an understanding of acceleration of bodies during free fall. All bodies near the earth's surface fall at an increasing rate of speed which is 32 ft/sec/sec.

7. Sir Isaac Newton proposed the first explanation that adequately accounts for the motions of the solar system. Newton's law of gravitation led to an explanation for the movements of all observable bodies. Newton's mathematical expression of his law is: $F :: \frac{M \times m}{d^2}$.

8. The planets are held in the solar system and their movements are governed by the gravitational attraction of the massive sun. Inertia carries a planet forward; gravitation pulls the planet inward. The resultant of these two forces and variation in speed causes elliptical orbits.

9. Time is measured by motions of the earth. The earth revolves around the sun in 365¼ days, a period of one year. The moon revolves around the earth in a period known as one lunar month. The earth rotates on its axis in a unit of time known as one day.

10. The center of gravity for the earth-moon system is 3,000 miles closer to the moon than the true center of the earth is. The earth-moon relationship causes an imbalance in the rotation of the earth.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

acceleration	inertia	physics
aphelion	lithology	planetesimals
center of gravity	mass	precession
condense	meteorology	satellite
eclipse	nebulae	scientific theory
gravity	nutation	terrestrial
hypothesis	perihelion	velocity

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Myths and legends are scientific explanations.
2. The nebulae in space contain mostly gases, but they also contain particles similar to the earth's matter.
3. The body in space known as the earth is a planet.
4. Cold gases tend to condense.
5. A hypothesis is based on more reliable information than a scientific theory.
6. As a result of his experiments, Galileo was able to explain why bodies fall toward the earth.
7. Newton discovered that all objects are attracted to all other objects.
8. The calendar month is not the same length as the moon's orbit around the earth.
9. The earth's greatest distance from the sun is 93 million miles.
10. All planets move counterclockwise around the sun.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. An idea which is thought to be true, but which cannot be demonstrated, is called a (*fact*, *hypothesis*, *philosophy*).
2. Clouds of gas and dust that exist in outer space are called (*planets*, *astronomical units*, *nebulae*).
3. The force which keeps the planets revolving around the sun is the result of the sun's gravitational attraction and the planet's (*atmosphere*, *inertia*, *rotation*).
4. The most accepted theory for the origin of the earth is the work of (*Newton and Galileo*, *Chamberlin and Moulton*, *Kuiper and Weizsacker*).
5. The center of gravity for the earth-moon system is (*3,000 miles below the surface of the earth*, *1,000 miles below the surface of the moon*, *3,000 miles nearer the moon than the true center of the earth is*).

6. The point in the earth's orbit where the earth is farthest from the sun is the (*perihelion, equinox, aphelion, plane of the ecliptic*).
7. Acceleration of any falling body near the earth's surface is *22ft/sec/sec, 32ft/sec/sec, 43ft/sec/sec*).
8. A lunar month is (*27⅓, 28⅖, 29½*) days.
9. The motion of the earth which in time will change the north star from Polaris to Vega is called (*precession, nutation, acceleration, revolution*).
10. The attraction between the sun and the earth is known as the force of (*acceleration, inertia, gravitation, velocity*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Time measured by sighting on stars is called __?__.
2. The scientist who was responsible for formulating the Law of Gravitation was __?__.
3. The force which acts along with the sun's gravitational attraction and keeps the planets revolving around the sun in elliptical orbits is __?__.
4. The formula for the gravitational attraction between observable bodies is __?__.
5. Because of __?__, all bodies resist movement.
6. The plane of the earth's orbit around the sun is the __?__.
7. The nodding of the axis of the earth because of the moon's influence is called __?__.
8. Scientific methods of study require both __?__ and __?__.
9. The 16th century scientist who advised students to follow scientific methods of study was __?__.
10. __?__ is the quantity of matter present in a body.

D. How and Why

1. If the sun were to lose mass but the earth stayed the same, what would happen? Why? If the earth were to lose mass but the sun stayed the same, what would happen? Why? Do the other bodies in the solar system have an attraction for one another?

2. Why did Severinus advise his students to go to the mountains, the valleys, the deserts, and the seashores for their information?
3. What was the most important contribution of Newtonian physics?
4. Why is the greatest concentration of gas in the center of the nebula?
5. Why do artificial satellites eventually fall toward the earth?
6. Why does the United States have more hours of daylight in June than in January?
7. Why are the orbits of the planets elliptical rather than circular?
8. Account for the fact that the sidereal year, month, and day is shorter than similar time units measured by sighting on the sun or moon.
9. Discuss the difference between a hypothesis, a scientific theory, and a scientific law.
10. How does modern scientific study differ from the study that preceded the sixteenth century?
11. Name some fields of study that are related to the study of the earth. What is each field concerned with? Why is the study of the earth broken down into many fields of study?

INVESTIGATIONS

1. Obtain information in a library about a myth which illustrates the ideas ancient men had about such things as earthquakes, volcanic eruptions, floods, seasonal changes, day and night, or the shape of the earth.
2. Discuss the difference between chemistry and physics. Is either science more closely related to earth science than the other is? Explain your answer.
3. Look up the word *philosophy* in a complete dictionary and discuss the meanings you find there. Is earth science a philosophy? Explain your answer.

INTERESTING READING

*Barnett, Lincoln, *The World We Live In.* New York: Golden Press, Inc., 1956.

Fenton, Carroll Lane, *Our Amazing Earth.* New York: Doubleday & Company, Inc., 1945.

Gamow, George, *A Planet Called Earth.* New York: Viking Press, Inc., 1963.

Gamow, George, *Gravity: Classic and Modern Views.* New York: Doubleday & Company, Inc., 1962.

Sutton, Felix, *The How and Why Wonder Book of Our Earth.* Columbus, Ohio: Charles E. Merrill Books, Inc., 1960.

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* Well-illustrated material.

Form and Layers of the Earth

Discovering the dimensions and the shape of the earth has been a difficult problem for students and for earth scientists. Measuring an object as large as the earth requires instruments that are not common. You would need a tape measure almost 25,000 mi long, to circle the earth at the equator. To measure the diameter, you would need more than 13 million yardsticks. Devices such as yardsticks or tape measures are neither accurate nor convenient for measuring objects as large as the earth. But the need for accuracy is increasingly important in an age of rapid transportation and space exploration. Without accurate instruments and earth measurements, planes would miss their landings, ships at sea could not be located, and spacecraft landing sites could not be computed exactly.

2:1 *Shape*

Earth's great size makes calculation of its dimensions difficult. Geodetic surveys supply accurate measurements made by modern methods.

Scientists are constantly trying to improve the accuracy of their measurements of the earth. The great dimensions involved in a survey of the earth are measured by a variety of instruments. The scientists making these measurements are *geodesists* (jee ahd′e sists), and the measurements themselves are a *geodetic* (jee a det′ik) *survey*.

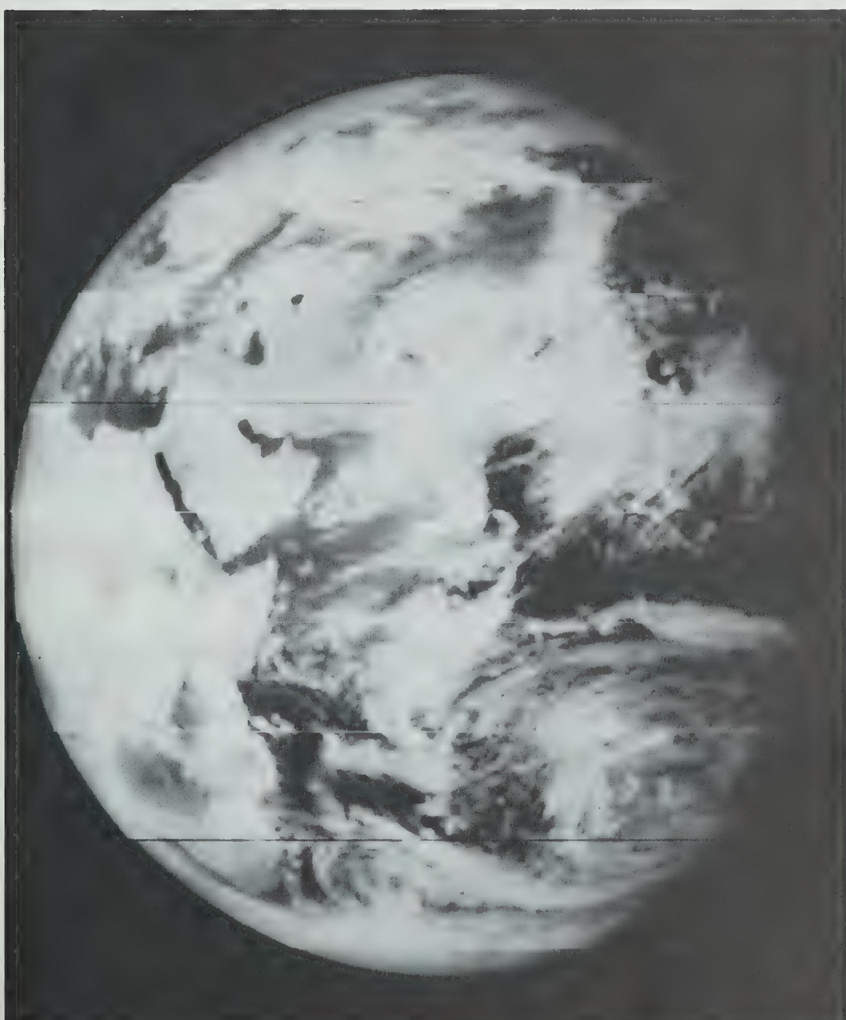
Today, few people have difficulty picturing the planet earth as a ball or *sphere* (sfir). Data relayed from artificial satellites and pictures taken by astronauts have confirmed the teaching of geography about the size and shape of the earth.

Even without modern instruments, satellites, and photographs, some ancient philosophers concluded that the earth is curved. About 500 B.C., Pythagoras, a Greek philosopher, concluded that the earth is a sphere by comparing the earth with

the spherical shape of the moon. Aristotle, another Greek teacher, who lived about 300 B.C., taught his students that the earth is a sphere. He based his conclusions on his observation of the moon during an eclipse. (Section 1:4.) Aristotle saw that the earth cast a curved shadow on the moon as the earth passed between the moon and the sun. About 200 B.C., Eratosthenes, an astronomer of Alexandria, Egypt, not only demonstrated the earth's curvature, but also computed its size.

By studying the shape of the moon and watching eclipses, ancient philosophers concluded that the earth is a sphere.

Scientists were not alone in recognizing that the earth is curved. A few observant sailors knew that the earth is not flat. If you have watched a ship sail away from shore toward the horizon, you may have seen the effect of the curvature of the



NASA

Figure 2-1. View of the earth from 215,000 miles above its surface. The sunlit side covers approximately 5/6 of the full hemisphere. The sunlit portion extends from 14° west longitude to about 135° east longitude with solar noon over the center of Saudi Arabia and the north pole near the top.

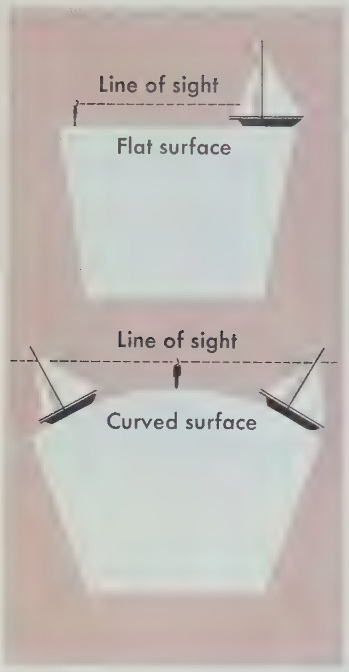


Figure 2-2. Around 500 B.C., Philolaus correctly guessed the earth to have the shape of a ball. Others thought the earth was a flat circular plate or short cylinder, floating in and surrounded by water.

earth. As the ship sails away, first the hull disappears from view, then the superstructure disappears below the horizon. As the ship approaches the shore, the superstructure comes into view first, then more and more of the hull appears, until finally the entire ship becomes visible. (Figure 2–2.)

Unfortunately, much of the early knowledge of the earth was lost in the six centuries after the fall of the Roman Empire (A.D. 476). This period is suitably called the Dark Ages. Many records of Greek and Roman culture were burned; others were hidden away in monasteries. Few people could read the language in which the records were written, even after they were found. Mere existence was a problem during this difficult period in the earth's history and the skills of the past were forgotten. People were confined to their immediate area of land. Without ocean travel, they did not realize that the earth is curved.

When Columbus sailed westward from Spain in search of India in 1492, he began a great period of exploration and investigation. Many discoveries about the earth followed. In 1522, Magellan, a Portuguese navigator, proved the earth to be spherical by sailing completely around it. Magellan had no measurements to determine the exact shape of the earth, but his successful circumnavigation of the globe supported the idea that the earth was a sphere. Eventually, enough evidence was obtained to show that the earth is an *oblate spheroid* and not a true sphere. An **oblate spheroid** (ahb′laet · sfir′awid) is a sphere that bulges at the equator and is flattened at the poles.

Jean Richer, using a pendulum clock, proved that gravitational attraction of the earth is less at the equator than at points distant from the equator.

Evidence of the bulge at the equator was the result of a scientific expedition sponsored by the French Academy of Science in 1672. Jean Richer, a French astronomer, went to French Guiana to observe the planet Mars. During his astronomical studies, Richer noticed that his pendulum clock lost about 2½ minutes per day. Pendulum clocks depend on gravity and they are accurate unless the force of gravity varies. A *pendulum* (pen′je lum) is a mass suspended on a long wire. The wire hangs from a point so that the mass can swing freely in a circular arc. Gravity pulls the pendulum toward its rest position, but inertia carries the pendulum beyond its rest position until gravity pulls it back toward its rest position again. Thus, the pendulum swings back and forth in an arc. The time required for the complete swing of the pendulum is called its *period.* The period of a pendulum depends upon the length of the pendulum wire and the gravitational attraction of the earth.

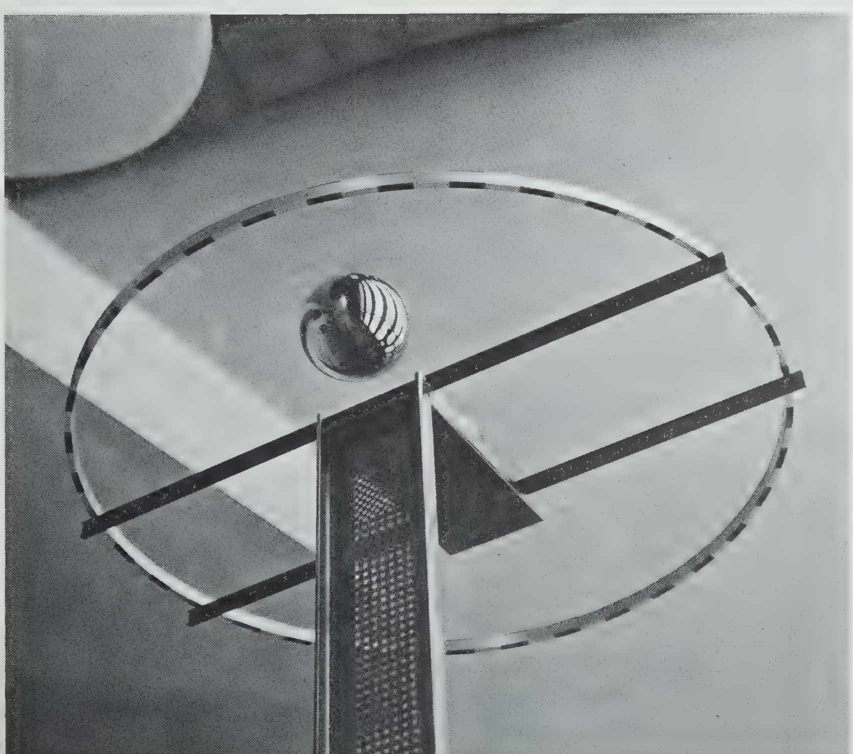
Richer knew that the length of the pendulum had not changed. The clock had not been damaged in shipment. Therefore, the difference in period must have been related to a change in the gravitational attraction of the earth. Richer concluded that the force of gravity was weaker in French Guiana, near the equator, than in Paris, nearly 3,700 mi north of the equator.

Rotational speed of the earth at points between the equator and the poles is less than 1,000 mi/hr and greater than zero. Exact rotational speed depends on latitude.

Sir Isaac Newton suggested a reason for the weaker gravitational attraction at the equator. He proposed that the earth bulges at the equator. Newton reasoned that near the equator the rotational speed of 1,000 mi/hr partially overcomes the pull of gravity toward the center of the earth. This force pulling matter away from the center of the earth is called **centrifugal** (sen trif′ye gal) **force**. Consequently, matter tends to bulge outward around the equator. Particles of matter at the poles are pulled toward the center of the earth more than at the equator because gravity is the only acting force. Therefore, the poles should be flatter than the equator. According to Newton's reasoning, the diameter of the earth should be greater at the equator than at the poles because of the equatorial

Centrifugal means to flee from the center.

The diameter of a sphere is a straight line moving from one surface to the other through the center of the sphere.



United Nations

Figure 2-3. The Foucault pendulum appears to shift its plane gradually clockwise, but the plane in which the pendulum swings does not change. Instead the earth beneath is rotating and causing the apparent shift.

$$F :: \frac{M \times m}{d^2}$$

bulge. In Newton's law of gravitation (Section 1:3), the gravitational attraction between two objects decreases as the distance between the two objects increases. This is another reason that the gravitational attraction for bodies on the earth's surface is least at the equator and greatest at the poles. (Figure 2–4.)

Not all scientists accepted Newton's idea about the shape of the earth. To settle the question, expeditions were sent out to make actual measurements. These expeditions were sponsored by the French Royal Academy of Sciences. In 1735, one group went to Peru (now Ecuador), near the equator; the other group went to Lapland, above the Arctic Circle, near the Gulf of Bothnia. The purpose of the expeditions was to measure the width of one degree (1°) of latitude. If the earth were a perfect sphere, the widths would not vary. If the earth were an oblate spheroid, the widths would increase toward the poles.

The equator divides the globe into north and south latitudes. Imaginary lines (latitude and longitude) divide the earth into units for convenience in locating places on the globe and for measuring time.

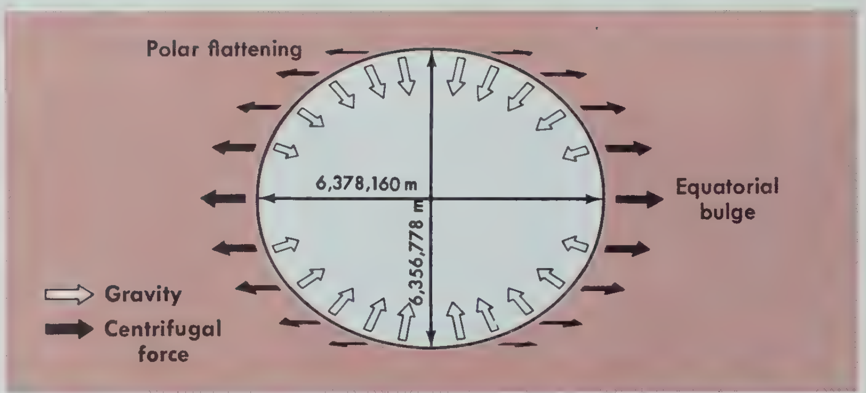


Figure 2-4. From the equator to the pole, the decrease in radius of the earth causes a change in weight of 0.5 percent.

Both the expedition in the Arctic and the one near the equator measured 1° latitude along a line of longitude. These are the results of their measurements:

Near the equator, 1° latitude = 68.704 mi
Near the north pole, 1° latitude = 69.407 mi

These measurements were additional proof that the earth is an oblate spheroid and not a perfect sphere.

Latitude lines would always intercept the same distances on the earth's surface if the earth were a perfect sphere. An arc of 1° intercepts distances that increase in length toward the poles.

Recent data from satellites indicate that the southern hemisphere is slightly larger than the northern hemisphere. From these data, the planet earth has been described as pear-shaped. However, the difference between the hemispheres is so slight that oblate spheroid is still the most accurate description of the shape of the earth.

Latitude and *longitude* are imaginary lines which divide the earth into equal units. Lines of **latitude** (parallels) run east and west parallel to the equator. Latitude is read in degrees north in the northern hemisphere and in degrees south in the southern hemisphere. The equator is the zero latitude or zero parallel. The north pole lies at 90° north latitude; the south pole is at 90° south latitude. Lines of **longitude** (meridians) run north to south from pole to pole and divide the earth into 24 units, each of which is 15° wide ($15° \times 24 = 360°$). The meridian that passes through Greenwich (Grin′ij), England, is known as the *prime meridian* (0°). (Figure 2–5.) Degrees are labeled east or west from Greenwich to the *international date line* which is a continuation of the prime meridian on the opposite side (Pacific Ocean side) of the globe. Thus, the international date line is approximately 180° east or west of the prime meridian. It varies slightly through unpopulated areas. For each 15° of longitude, there is 1 hr of difference in time from the previous meridian. At the international date line, one day is lost or gained, depending upon the direction of travel.

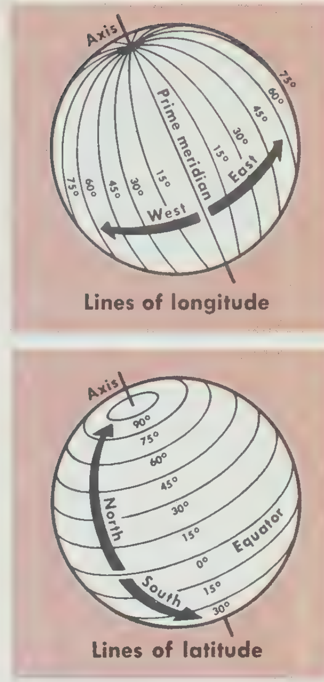


Figure 2-5. Positions of latitude could be determined when altitude of sun and stars had been measured by means of telescopic observations. Longitude positions lie on great circles that pass through both poles.

PROBLEMS

1. When it is 12 noon on Sunday at 90° west longitude, what time is it at 90° east longitude? Is it the same day at Greenwich, England?
2. On a map of the world, draw 24 equal longitude lines. How many degrees apart are they?
3. Assume that you leave Greenwich, England, at midnight and fly west at a rate of 1,000 mi/hr along a latitude line where the circumference of the earth measures exactly 24,000 mi. Give the hour at which you arrive at each of the longitude lines on the map. How many hours will it take you to return to your starting point? On which day and hour would you arrive in Greenwich, England, if you left there at 6 A.M. on Monday, June 1?

2:2 *Size*

Study of the shape of the earth led to questions about the size of the earth. From repeated scientific measurements, man's knowledge of the size of the earth increased. Ancient maps show far different outlines for the continents and the oceans than do modern maps. Values for the size of the earth have also undergone change.

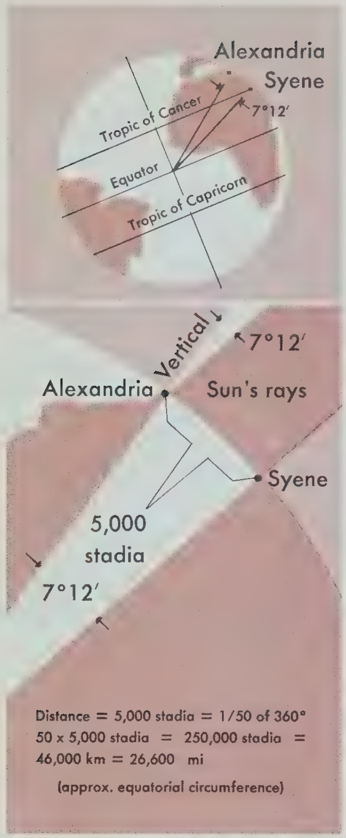


Figure 2-6. Medieval figures for the earth's circumference were much smaller than Eratosthenes' nearly accurate calculations.

The circumference of the earth at the equator is approximately 24,902 mi.

About 200 B.C., the Greek astronomer Eratosthenes made the first measurements of the earth's circumference. His results were amazingly close to the presently accepted figures. The slight difference may be because the *stadium* (staed′ee um), an ancient unit of distance equal to approximately 185 meters, cannot be directly related to our modern units of distance.* Also, Eratosthenes may not have measured accurately the distance between Alexandria and Syene (now Aswân), Egypt. Another variable is that the well walls may not have been perfectly perpendicular.

Eratosthenes knew that Syene (Sie ee′nee) was about 5,000 stadia south of Alexandria. He also knew that at noon on the vernal equinox the sun shined directly into a deep well in Syene and cast no shadow. At noon on the same day in Alexandria, the sun did cast a shadow. Eratosthenes determined that the angle between the sun's rays and a vertical post was seven degrees twelve minutes (7° 12′). Assuming that because of the sun's great distance from earth all rays from the sun are nearly parallel, Eratosthenes reasoned that the earth must be curved, since the sun's rays were perpendicular to earth at Syene and they made an angle with earth at Alexandria. (Figure 2–6.)

He calculated that an angle of 7° 12′ was equal to 1/50 of the 360° in the circumference of a circle:

$$\frac{7^\circ\ 12'}{360^\circ} = \frac{7.2^\circ}{360^\circ} = 1/50$$

Therefore, the distance of 5,000 stadia between Alexandria and Syene was an arc equal to 1/50 of the circumference of the earth. If stadia are converted to miles, Eratosthenes' measurement is equal to 26,660 mi (approximately). This value is close to the 24,902 mi (approximately) now considered to be the correct circumference of the earth at the equator.

Although Eratosthenes' measurements of the earth were nearly exact, the data were not well known. Eratosthenes' measurements were not used in making early maps, and ancient maps were extremely inaccurate. Furthermore, the data were lost during the Dark Ages. During the nineteenth century, new measurements of the earth were made.

Eratosthenes' method of computing the size of the earth is still used. For greater accuracy, sightings today are made with a star as a reference point rather than the sun.

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* See Appendix A, p. 506.

In 1830, Sir George Everest, the British surveyor after whom Mt. Everest was named, calculated values for the size of the earth that are still used. In 1909, the United States Geological Survey computed another series of values which was adopted in 1924 as the International Standard. These figures are still in use, although they were revised in 1960 by the United States Army Map Service. Data from earth satellites were used for the latest revision. (Table 2–1 and 2–2.) Differences in the values represent variations in technique and instruments rather than actual changes in earth's size.

Earth measurements are always subject to revision in light of new data.

Table 2–1. *Values for Earth's Axes*

	North-South Axis	*Equatorial Axis*
Everest (1830)	6,356,075 m	6,377,276 m
International Standard (1909)	6,356,912 m	6,378,388 m
U.S. Army Map Service (1960)	6,356,778 m	6,378,160 m

Table 2–2. *Values for Earth's Radii**

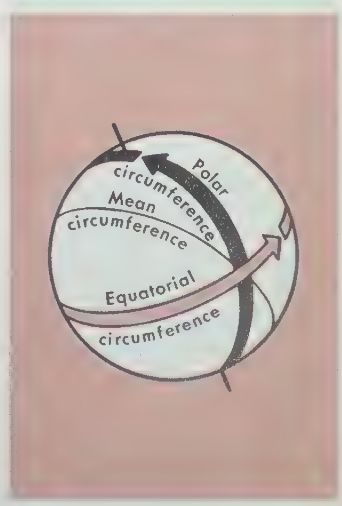
Polar radius	3,951 mi	6,357 km
Equatorial radius	3,964 mi	6,378 km
Mean radius	3,960 mi	6,367 km

* As adopted by the International Union of Geodesy and Geophysics.

The values in Table 2–2 are used to determine approximate values ≅ of earth measurements as follows:

$$\text{Equatorial circumference} = 2\,\pi\,r \cong 2 \times 3.14 \times 3{,}964 \text{ mi} \cong 24{,}902 \text{ mi}$$
$$\text{Polar circumference} = 2\,\pi\,r \cong 2 \times 3.14 \times 3{,}951 \text{ mi} \cong 24{,}860 \text{ mi}$$
$$\text{Area} = 4\,\pi\,r^2 \cong 4 \times 3.14 \times (3{,}960 \text{ mi})^2 \cong 197{,}000{,}000 \text{ mi}^2$$
$$\text{Volume} = \frac{4\,\pi\,r^3}{3} \cong \frac{4 \times 3.14 \times (3{,}960)^3}{3} \cong 260 \text{ billion mi}^3$$

Figure 2-7. Differences between the polar circumference and the equatorial circumference are so slight that the earth viewed from space appears nearly spherical.



Problem

If the angle measured by Eratosthenes had been 10° instead of 7° 12′ and the distance had been 5,000 stadia, what would the value of the circumference of the earth have been? Give the answer in kilometers.

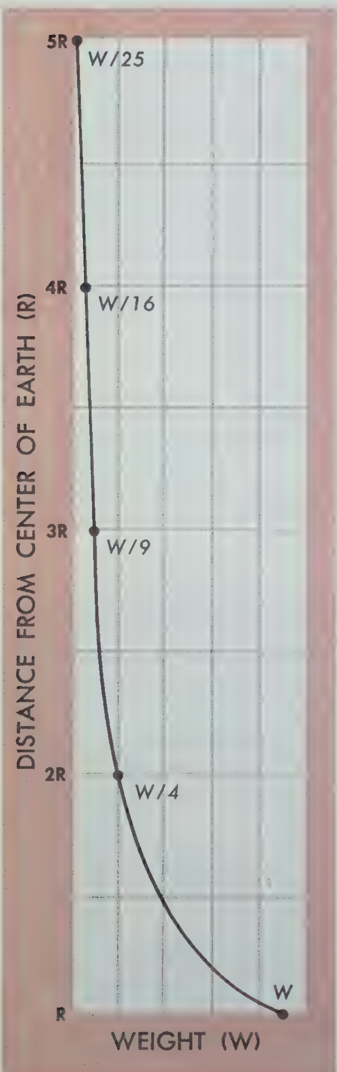
2:3 Mass

Mass and weight are not the same.

Knowledge of the size and shape of the earth made it possible to measure its mass. **Mass** is the amount of matter present in a body. It is a physical property that depends on the number, kind, and arrangement of particles within the body. Mass is also described as *inertia*, the resistance a body offers to movement. (Section 1:3.) Greater force is required to move a heavy oı dense body than is required to move a light-weight or less dense body. The mass of a body may be measured on a balance by comparing it with the mass of an international standard.

Mass and weight are two terms which are often used interchangeably. But mass and weight are not the same. **Weight** on the earth is the gravitational attraction of the earth for an object on or near its surface. Mass is a constant property, but weight is a changing property. The weight of a body changes with its distance from the center of the earth. (Figure 2–8.) A body weighs more at sea level than on a mountain top; it weighs more at the poles than at the equator. Weight may be measured with a spring scale. The greater the gravitational attraction of the earth for the body, the more the spring is pulled downward. A balance that measures mass will register the same measurement for a body at any latitude or elevation.

Figure 2-8. As the distance from the center of the earth increases, the weight of a body decreases.



Measurement of the mass of the earth is made by indirect methods. If man had an extremely sensitive instrument, he could compute earth's mass from the length of a pendulum and the amount of its *deflection* (di flek'shun) toward another body. However, the amount of deflection is too small to be measured accurately. Although the calculations are simple, the actual measurements are complex.

Accurate measurements of earth's mass have been made in a more practical way on a beam balance devised in 1914 by John Henry Poynting, a British physicist. (Figure 2–9.) With the Poynting balance, the difference between the gravitational pull of the earth and the gravitational pull of a second large mass was determined. A large mass was placed on one pan of the balance. Then weights were placed on the other pan until both pans were balanced. A second larger mass was placed beneath one pan and the distance between the first mass and the second mass was measured. Then weights were added to the other pan to balance the beam which had been disturbed by the presence of the second mass. The additional weights represented the gravitational attraction between the mass on the pan and

the mass below it. All measurements, except the mass of the earth, had been determined. The mass of the earth was found by using the following formula:

$$\frac{M_1 \times M_2}{d^2} = \frac{M \times m}{r^2}$$

In this equation, M_1 represents the first mass, M_2 represents the second mass, M represents the mass of the earth, m represents the weights added to achieve balance after placing the second mass below the pan, d represents the distance between the centers of M_1 and M_2, and r represents the radius of the earth. Solving the equation for M, the mass of the planet earth is found to be approximately 6.6 x 10^{21} tons or 6.6 sextillion tons (6,600,000,000,000,000,000,000 tons).

Mass of a body divided by its volume gives a ratio which represents the density of the body.

$$D = \frac{M}{V}$$

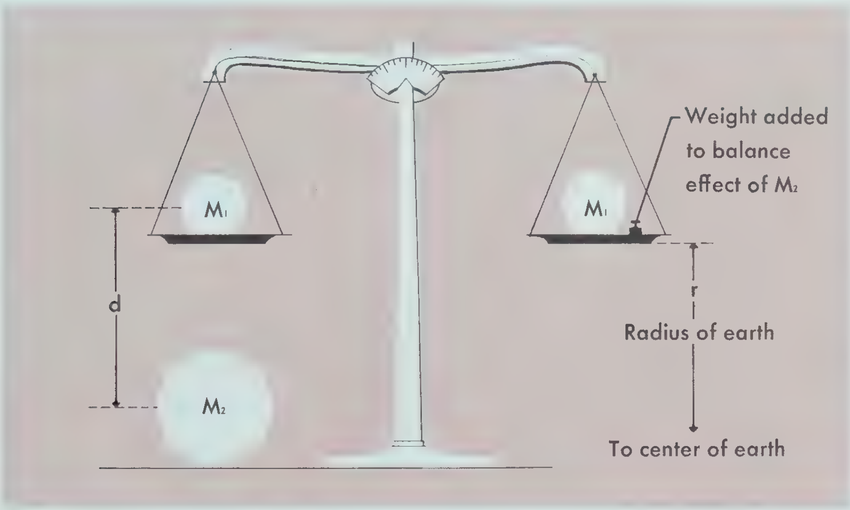


Figure 2-9. Poynting experimented for 12 years before he was able to demonstrate the method by which mass of the earth has been determined.

2:4 *Density*

After the mass of the earth was determined, its density could be calculated. **Density** is the mass of a body divided by its volume, or mass per unit volume. Density is expressed in grams per cubic centimeter (g/cm^3), pounds per cubic feet (lb/ft^3), or any other similar ratio of units in the same system. For example, the density of water may be expressed as 62.4 lb/ft^3, or 1.0 g/cm^3, or 8.3 lb/gal.

Density of water is 1.0 g/cm^3 or 62.4 lb/ft^3.

To find the density of the earth, its mass of 6.6 sextillion tons is divided by its volume of 260 billion mi^3. If tons are converted to grams and cubic miles are converted to cubic centimeters, the density of the earth is found to equal 5.52 g/cm^3.

Average density of the earth is 5.52 g/cm^3.

Specific gravity is a comparison between the mass of a body and the mass of an equal volume of water.

Specific gravity is the ratio between the mass of a given substance and the mass of an equal volume of water. Specific gravity is not expressed in units. It is simply a ratio that indicates whether a given substance is heavier or lighter than water. Because the density of water at 4°C (39°F) is 1 g/cm^3, it is a convenient unit for comparison. The density of the earth is 5.52 times the density of water. Therefore, the specific gravity of the earth is 5.52. That is, the matter of the earth is 5.52 times as heavy or dense as water. (Table 2–3.)

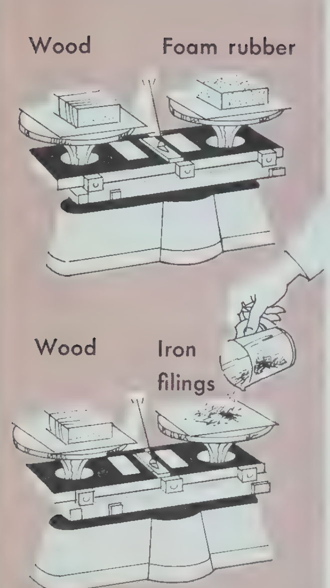


Figure 2-10.

EXPERIMENT. Cut a block of wood and a block of foam rubber to the same size (volume). Cover each of the pans of a laboratory balance with a piece of paper. Put the block of wood on one pan and the block of rubber on the other pan. Which has the greater mass? Which weighs more? Remove the rubber block and add enough iron filings to the paper on the pan to balance the wood block. Compare the volume of the wood block with the volume of the iron filings. Which has the greater volume? Compare the density of the rubber, the wood, and the iron. What effect does size have on density?

Problem

Find the density of a 1,120 lb rock that has the dimensions 3 m by 4 m by 2 m. What is the density in pounds per cubic feet? What is the specific gravity of the rock?

Table 2–3. *The Earth*

Mean diameter	7,920 mi	12,734 km
Circumference (polar)	24,860 mi	40,009 km
Circumference (equatorial)	24,902 mi	40,076 km
Density	344.7 lbs/ft^3	5.52 g/cm^3
Area of surface	197,000,000 mi^2	510,000,000 km^2
Volume	26 x 10^{10} mi^3	11 x 10^{11} km^3
Mass	6.6 x 10^{21} tons	6 x 10^{24} kg
Atmospheric pressure at sea level (decreases approximately 0.5 lb/in.^{2} for every 3.5 mi above sea level)	14.7 lb/in.^{2}	1,033.4 g/cm^2
Mean temperature (increases approximately 1°F, or 0.56°C, for every 60 ft below the surface)		

2:5 Layers

Information about the interior of the earth has been obtained by indirect methods. Geophysicists have analyzed vibrations coming from within the earth during earthquakes by means of an instrument called a *seismograph* (siez'ma graf). A seismograph produces a recording called a *seismogram.* Seismograms indicate that the interior of the earth has layers of different densities. Rocks at the surface are the least dense (approximately 2.7 g/cm^3). Densities increase downward until, at the center of the earth, the density is approximately 11.5 g/cm^3.

Geophysicists are scientists who study the physics of the earth, particularly the matter and motions of the earth.

Figure 2–11 shows the distribution of densities within the earth as suggested by seismographic studies. The **crust**, the outer layer of the earth, is the only layer about which scientists have direct knowledge. Materials of the crust remain in a solid state because both temperature and pressure are relatively low. The **mantle**, the layer directly beneath the crust, has some properties of a solid and some properties of a plastic or pliable material. Density of the mantle increases with depth. At the base of the crust, the density of the mantle is 3.5 g/cm^3. At the contact between the **outer core** and the mantle, the density of the mantle is 5.5 g/cm^3. The outer core is believed to be in the liquid state. Its density increases with depth from 9.5 g/cm^3 at its contact with the base of the mantle to 11.5 g/cm^3 at its contact with the inner core. Density of the inner core is approximately 11.5 g/cm^3. Data from seismograms suggest that the inner core is in the solid state.

Information about the layers of the earth is obtained from data recorded by a seismograph.

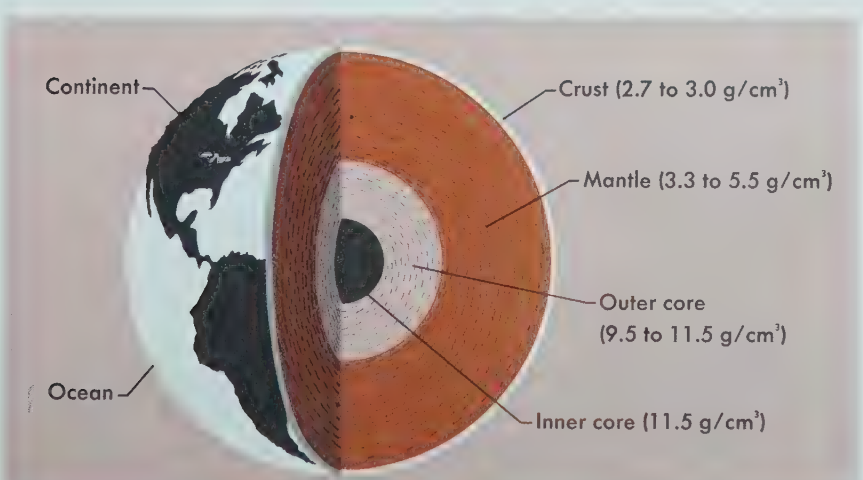


Figure 2-11. Densities computed for the earth's interior are believed to be accurate to within about 10 percent.

Mantle of the earth appears to be composed of peridotite.

Iron has a density of about 7.8 g/cm³. The inner core density of about 11.5 g/cm³ is possible if pressure is considered.

Density is the only clue to the composition of the inner layers of the earth. Geologists have suggested that the mantle has a composition similar to the rock known as *peridotite* (pa rid′a tiet) (Section 5:5) because the densities are the same. On the basis of recorded densities, geologists also suggest that the core may be mostly iron and nickel.

EXPERIMENT. Put ¼ cup of water, ¼ cup of cooking oil, and ¼ cup of iron filings in a glass jar. Shake the jar and let it stand for 15 or 20 minutes. How are the substances arranged in the jar? Do you need to weigh the substances to determine their relative densities? Put the block of wood, the block of foam rubber, and the iron filings used in the experiment in Section 2:4 in a dry glass jar. Shake the jar and observe the arrangement of the materials. Are these substances arranged according to density? Why do liquids rearrange themselves in order of density?

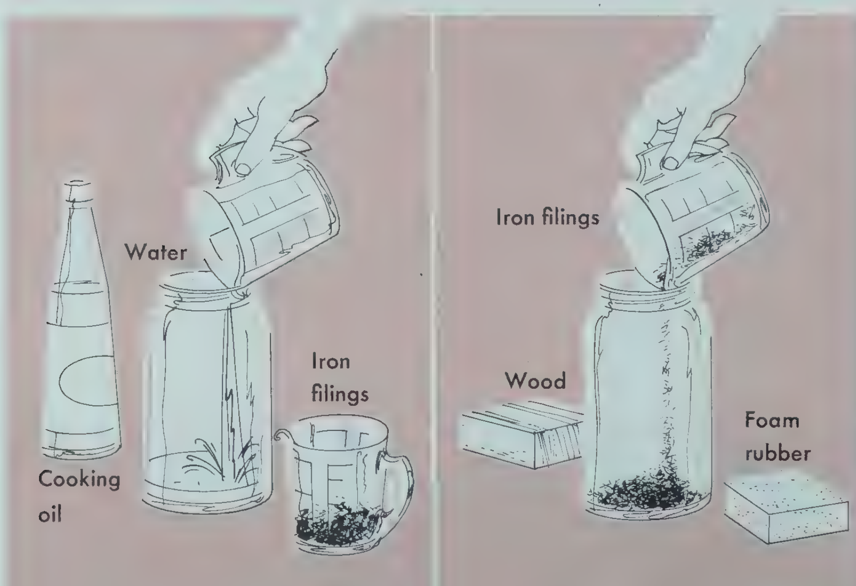


Figure 2-12.

PROBLEM

Examine the diagram of the layers of the earth in Figure 2–11. Offer an explanation for the arrangement of the layers with the iron-nickel core at the center.

MAIN IDEAS

1. As early as 500 B.C., philosophers and scholars were convinced that the earth is a sphere.
2. Columbus' voyages indicated that the earth is not flat, and Magellan supported the idea that the earth is a sphere by sailing around it.
3. The force of gravity is less at the equator than at other latitudes because the earth is an oblate spheroid which bulges in the region of the equator.
4. The imaginary surface line called the equator divides the earth into north latitude and south latitude.
5. Imaginary surface lines running from pole to pole divide the earth into east longitude and west longitude. The plane of the prime meridian, the longitude line at Greenwich, England, extended to the opposite side of the globe forms the international date line.
6. The circumference of the earth as calculated by modern methods is approximately 24,902 mi.
7. The mass or amount of matter in the earth is approximately 6.6 sextillion tons.
8. Weight changes with distance from the center of the earth because of the changing of the force of gravity. However, mass does not change.
9. The average density of the earth (mass divided by volume) is 5.52 g/cm^3.
10. Specific gravity is a comparison between the mass of a body and the mass of an equal volume of water. The specific gravity of the earth is 5.52; that is, 5.52 times the mass of an equal volume of water.
11. According to seismographic studies, the density of the matter of the earth increases from 2.7 g/cm^3 at the surface to 11.5 g/cm^3 at the center.
12. Information about the interior of the earth is obtained by seismographs. The core of the earth is probably a combination of iron and nickel.
13. Earth is sometimes described as pear-shaped because the southern hemisphere of the earth is larger than the northern hemisphere. However, oblate spheroid is a more accurate term to use.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

crust	mass
deflection	oblate spheroid
density	pendulum
geodesists	period
international date line	prime meridian
latitude	seismograph
longitude	specific gravity
mantle	weight

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. The period called the Dark Ages preceded the age of the Greek scholars.
2. A pendulum swings back and forth because of the forces of gravity and inertia.
3. At the equator, the same pendulum swings more slowly than it does at the poles.
4. Measurements of mass and weight are identical at all points on the surface of the earth.
5. Density of a substance depends upon its mass and its volume.
6. The specific gravity of a substance is expressed in units, such as pounds or grams.
7. The interior of the earth is divided into exact layers of equal depths.
8. The most recent data indicate that the earth is slightly pear-shaped.
9. The interior of the earth is much more dense than 2.7 g/cm^3, the density of the crust.
10. Rocks in the outer layer of earth appear to have crystallized because of low temperature and little pressure.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. The average density of the earth is about (*3.4 g/cm³, 5.5 g/cm³, 7.5 g/cm³*).
2. The layer of the earth about 1,800 miles below the surface is the (*mantle, outer core, inner core*).
3. The density of the mantle is believed to be (*less than, more than, the same as*) the density of the core.
4. The true shape of the earth is a(n) (*sphere, oval, oblate spheroid, plane*).
5. If you are traveling from east to west and you cross the international date line, you (*lose one, gain one, lose two, gain two*) day(s).
6. Distances north or south of the equator are measured on (*latitude lines, longitude lines, seismograms, meridians*).
7. The amount of matter in a given body is its (*weight, mass, volume*).
8. The measurement which changes with distance from the center of the earth is (*weight, mass, volume*).
9. The property of matter which resists movement is (*acceleration, inertia, density*).
10. The force of gravity (*increases, decreases, remains the same*) with an increase in mass.

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The circumference of the earth is about __?__ miles.
2. Density of a body is its __?__ divided by its __?__.
3. Specific gravity is the mass of a substance compared to the mass of an equal volume of __?__.
4. Magellan's circumnavigation of the earth suggested that the earth is __?__.
5. The period of a pendulum depends upon the __?__ of the pendulum and the __?__ of the earth.

6. The forces which cause the earth to bulge at the equator are __?__ and __?__.
7. Information about the interior of the earth is obtained from earthquake tremors that are recorded by a __?__.
8. The layers of the earth are called the __?__, __?__, __?__, and __?__.
9. The density of the earth __?__ with depth.
10. __?__ as well as __?__ of an object may be determined with a balance; __?__ of an object may be measured with a spring scale.

D. How and Why

1. What evidence have you observed to indicate that the earth is a sphere?
2. What causes a pendulum to swing back and forth in a regular period?
3. Why does time change when you cross the international date line?
4. On a world globe, find the latitude and longitude of your own locality.
5. Why is it important that the earth's size and shape be measured accurately?
6. Would you weigh less or more on the top of Mt. Everest than in your own home? Why do astronauts experience weightlessness?
7. What measurements must you know to calculate the density of a body? What measurements do you need to know to compute the specific gravity of a body?
8. How has information about the density of materials inside the earth been obtained?
9. Why are scientists convinced that the crust, the mantle, and the inner core show increasing densities with depth?
10. Do scientists actually know what kinds of materials are present in the interior of the earth?
11. Explain the difference between mass and weight. How have measurements of the earth's mass been obtained?
12. Why did Newton first propose that earth bulges at the equator? How was it proved that the planet earth has an equatorial bulge?

INVESTIGATIONS

1. Discuss several types of maps of the earth: a globe, a relief map, a homolographic projection, and a Mercator projection. Which map would be best for a sailor? Which for a flier? Which would be most useful for short distances? Which would be best for a person walking? Which flat map gives the truest idea of what the land areas of the earth are like?
2. Plan a jet plane flight from New York to Paris and one from New York to San Francisco. Find out the usual time the flight takes and, using the same departure time for each trip, figure out what time you would arrive at each destination in their local time. If you were flying to Japan, what time and day would you arrive?

INTERESTING READING

Adler, Irving, *Seeing the Earth from Space*. New York: New American Library, Inc., 1962.

*Beiser, Arthur, *The Earth*. Life Nature Library. New York: Time, Inc., 1962.

Liberty, Gene, *The How and Why Wonder Book of Time*. Columbus, Ohio: Charles E. Merrill Books, Inc., 1963.

*Wyckoff, Jerome, *The Story of Geology: Our Changing Earth Through the Ages*. New York: Golden Press, 1960.

* Well-illustrated material.

The Lithosphere

> ***...one should be thoroughly acquainted with...the elements with which we are surrounded...***
>
> ***Jan Swammerdam (1637-1680)***

While some early scholars were seeking a way to measure objects as large as the earth and to penetrate distances too great for easy comprehension, other scientists were trying to define the basic substances of which all matter is composed. At one time, water was believed to be the basic substance; at another time, air was favored as the fundamental material. Aristotle proposed air, water, fire, and earth as basic elements because these four forms of matter were believed to compose the entire physical universe.

As telescopes changed men's concepts of space and the universe, so microscopes and chemical analyses changed men's ideas about which substances are elemental. Chemists and physicists have decomposed matter into its simplest forms, separated material into its most minute particles, and isolated those particles. Recognition of the atom as the basis upon which elements depend led to the awareness of subatomic particles. Now atomic science discloses that still smaller particles exist.

All matter appears to be composed of the same basic elementary particles. Your environment offers these elements in a wide variety of shapes and combinations. To become thoroughly acquainted with the elements which surround you, study and investigate "terra firma," the solid earth.

UNIT Two

Matter

Look about you. How many different kinds of things can you see? In ancient times fire, water, air, and earth were considered the basic materials from which all things were made. Fire, water, air, and earth are completely different in their appearance and in the way they behave. The relationships among the varied things of the earth have challenged scientists from the time of the early Greek philosophers to the present. Like Severinus, scientists have gone to the mountains, the seashores, the deserts, and the laboratories to investigate the nature of earth's materials. Many questions are still unanswered, but scientists are learning gradually to understand matter.

When Severinus advised his students to gain a knowledge of "things" and their properties, he was telling them to study matter. Everything that Severinus mentioned—the mountains, valleys, deserts, shores, plants, animals, and minerals—is composed of matter. Each kind of matter is recognized by its physical characteristics and its behavior.

3:1 *Kinds of Matter*

Matter exists in several forms including mixtures, chemical compounds, and elements.

Matter is anything that has mass and occupies space. **Matter** is also defined as anything that has inertia, or that resists movement or a change in the direction of movement. Matter is the term used by scientists to include all known materials of whatever origin. Matter exists in an almost limitless variety of patterns. Much of the matter of the earth consists of rocks and minerals. Matter also includes air, water, and all living things. The forms of matter include mixtures, chemical compounds, and elements.

Oregon State Highway Department

Figure 3-1. Matter includes all known materials of the earth. What kinds of matter are present in this coastal seascape?

Mixtures are combinations of different kinds of particles that may be separated into their component parts by a manual process.

Mixtures consist of a variety of particles combined in any proportions. Each particle in a mixture has recognizable boundaries or edges. One familiar mixture is soil, a combination of decayed plant and animal matter and eroded rock. Another common mixture is rock, which is a combination of minerals. Particles in a mixture can be separated by a mechanical or manual process. Rocks can be broken apart into individual mineral grains. Soil and water can be separated by allowing the soil to settle and pouring off the water.

Compounds are combinations of elements in which definite ratios of elements are present.

Compounds differ from mixtures in that they are composed of two or more basic substances in a definite ratio by weight. Common table salt is a compound, and so is water. Neither salt nor water can be broken down into its different kinds of particles through a mechanical process. However, compounds can be changed into simpler components (kam poh′nents) called *elements* (el′e ments) through chemical reactions. Components separated from a compound through a chemical process are completely different from the original compound. Salt can be separated into its components, sodium and chlorine. Sodium is a white metal; chlorine is a dark gas with a pungent (pun′jent) odor. Water can be separated into its components, hydrogen and oxygen. Both hydrogen and oxygen are gases and are completely different from water, a liquid.

Elements are unique substances that cannot be separated into simpler components by either chemical or mechanical means.

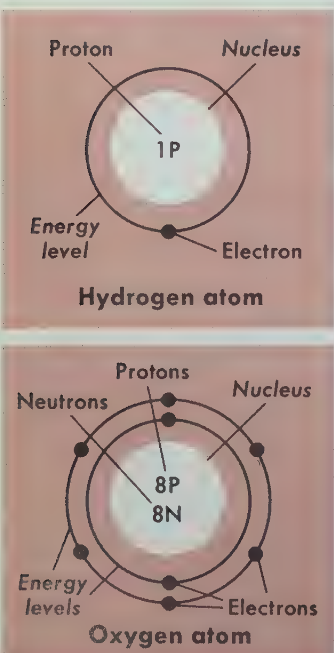
Elements are the basic materials of the earth. Each element differs from all others. Sodium, chlorine, hydrogen, and oxygen are four of the more than one hundred known elements. The smallest unit in which an element can exist is an **atom.** Atoms may be compared to building blocks or bricks. A building made of one kind of brick is similar to an element. A building made of several kinds of brick is similar to a chemical compound. Atoms are like building blocks which can be combined into more complex forms of matter.

Atoms combine to form chemical compounds which are completely different from the combining elements, or atoms.

Atoms are the smallest units of an element that enter into chemical reactions. Compounds always consist of two or more kinds of atoms. **Molecules** (mahl′i keuls) are the smallest units of a compound. Molecules of most compounds can be separated into atoms of different elements through chemical reactions. Atoms of elements can also combine to form molecules, but the molecules of an element separate into atoms of the same kind. Both elements and compounds are called *substances.*

Elements cannot be reduced to simpler substances by either chemical or mechanical processes. However, atoms of elements are composed of many small particles called *subatomic particles.* All subatomic particles are too small to be seen with any known instrument. Only their behavior can be observed. Even atoms are too small to be observed by ordinary microscopes. Billions of atoms would be needed to cover the head of a pin. But in spite of the small sizes of atoms, scientists have obtained some idea of their size and shape through the use of X rays.

Figure 3-2. Each molecule of hydrogen gas (H_2) or oxygen gas (O_2) contains two atoms of the element.



Experiments indicate that atoms of elements consist of particles with different electrical properties. Three of the particles are the *protons* (proh′tahns), *neutrons* (neu′trahns), and *electrons* (i lek′trahns). **Protons** are positively charged particles; **electrons** are negatively charged particles; **neutrons** are particles with no electrical charge. Protons, electrons, and neutrons are the smallest particles of matter of interest in the study of rocks and minerals. Still smaller particles have been discovered, but they are not important now to your understanding of the earth's matter.

3:2 *Structure of Matter*

In 1913, Niels Bohr, a Danish physicist, described the hydrogen atom. His model of hydrogen led to our present ideas of atomic structure. In the Bohr model, the center of the atom is

pictured as a small, dense nucleus consisting of protons and neutrons. The nucleus contains 99.9 percent of the mass of the atom. The nucleus of the atom usually has a number of positive charges equal to the number of protons it contains. Because opposite electrical charges attract each other, the nucleus of an atom attracts a number of negatively charged electrons equal to the number of its protons.

Electrons vibrate around the nucleus at approximately the speed of light. Not all of the electrons move about the nucleus at the same distance from its center. Instead, electrons may vibrate in a series of shells called *energy levels*. The number of shells used by the electrons depends upon the number of electrons in the atom. An atom of hydrogen, which has only one electron, has just one shell. Other kinds of atoms may have as many as seven shells. Some electrons are close to the nucleus; other electrons are farther away. The average distance between the nucleus and the outermost electrons determines the size of the atom. Most of an atom is empty space between the electrons and the nucleus and between the electrons themselves. Nevertheless, an atom behaves as a unit.

Speed of light is about 186,000 mi/sec.

Bohr's model of the atom does not explain that electrons behave, in some ways, more like light waves than particles. Particles have true orbits, and it is possible to predict the position of the particle within the orbit at any moment. However, electrons move through space as waves, and the location of an electron cannot be determined exactly. Instead, its most probable location, or where the electron will be most often, determines the position of an energy level. The term *electron cloud* describes the movement of electrons better than the term electron orbit. Many physicists believe that electrons are vibrating particles that change position as energy levels change.

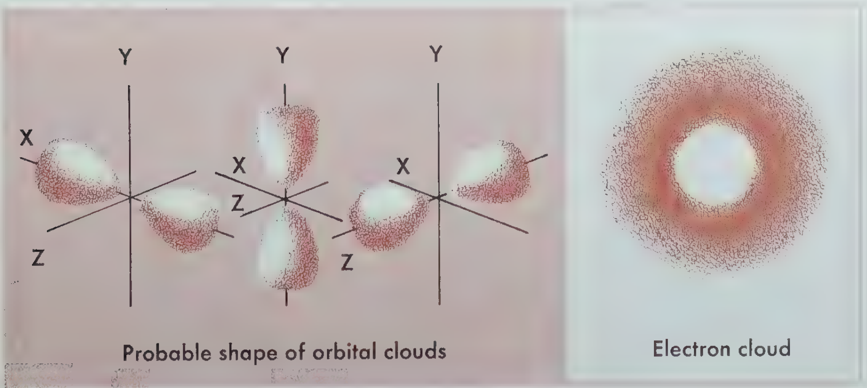


Figure 3-3. Orbitals form the electron cloud of the subshell. The clouds of all subshells in an atom form the spherical electron cloud.

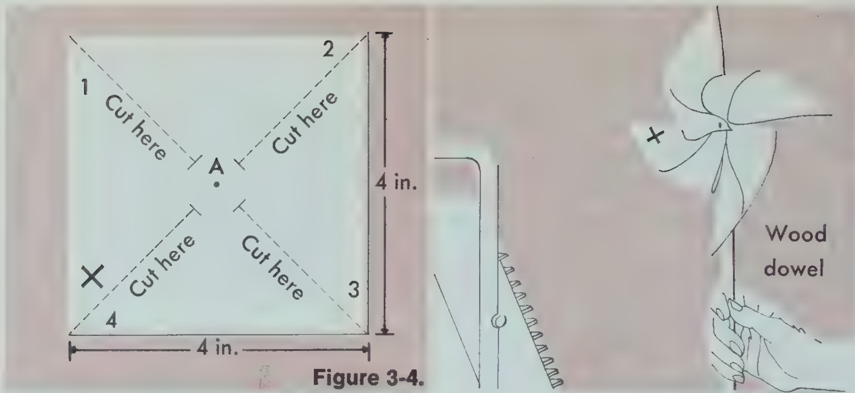


Figure 3-4.

EXPERIMENT. Purchase or construct a pinwheel. Place an X on one of its tips. (Figure 3–4.) Blow on the pinwheel or hold it in front of an electric fan until it is revolving as rapidly as possible. Have another student use a stopwatch or the second hand on a clock. Without stopping the pinwheel, plot the position of the X during a period of 60 sec. Describe the plot. Can you determine the exact position of the X while the pinwheel is in motion? Compare your results with the movement of an electron. What is similar to the electron movement? What is different from the electron movement?

Any given atom has a different mass from isotopes of the same element.

The number of protons is constant for each atom of a given element. The number of electrons is always equal to the number of protons. However, the number of neutrons may vary for atoms of the same element. **Isotopes** (ie′so tohps) are atoms of the same element that have different mass. The mass varies because each isotope has a different number of neutrons in its nucleus. Every element has at least two isotopes. For example, hydrogen has three isotopes. Most hydrogen atoms contain one proton, one electron, and no neutron; some hydrogen atoms have one proton, one electron, and one neutron; a few hydrogen atoms have one proton, one electron, and two neutrons.

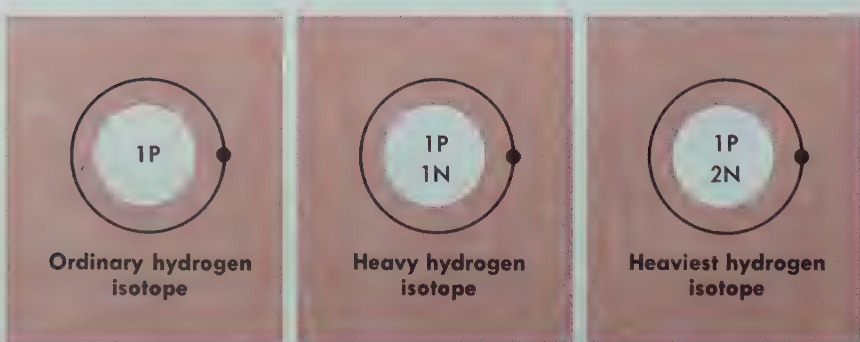


Figure 3-5. The hydrogen isotopes—protium, deuterium, and tritium—are alike in their chemical properties. How do they differ?

Neutrons and protons determine the mass of an atom. The mass of a proton is 1.672×10^{-24} g. A neutron has approximately the same mass as a proton. Both a proton and a neutron have a very small mass, but that small mass is 1837 times the mass of an electron. Thus, electrons are neglected in determining the mass of an atom because their mass is insignificant.

Subatomic particles are known through their electrical properties but are too small to be observed.

3:3 Chemical Properties

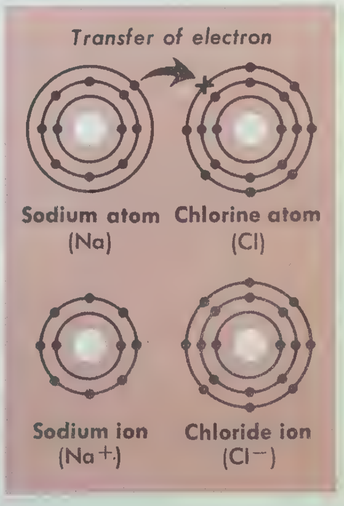
Although electron mass is insignificant, electrons in the outer shell of an atom control its chemical properties. *Chemical properties* determine the way an atom behaves in contact with other atoms; that is, whether the atom will unite with other atoms, go into solution, or substitute for another atom.

Behavior of an atom depends upon the number of electrons in its outer shell.

Each atom tends to have an equal number of protons and electrons. If positively charged protons are balanced by negatively charged electrons, the atom is said to be *stable* or electrically neutral. Sometimes atoms share electrons; these atoms are *unstable*. The process of filling the outer shell with electrons is known as a **chemical reaction.**

Some atoms lose electrons and become positively charged particles; other atoms gain electrons and become negatively charged particles. Both positively and negatively charged particles are called **ions** (ie′ans). Positively charged ions combine with negatively charged ions to form stable compounds. The number of positive charges is always balanced by an equal number of negative charges in a compound.

Figure 3-6. A positively charged sodium ion combines with a negatively charged chloride ion to form the stable compound sodium chloride, the mineral halite.



PROBLEMS

1. An atom of oxygen gains two electrons. What kind of charges does the oxide ion have? How many charges?
2. How many oxide ions are required to balance one silicon ion?
3. A sodium atom loses one electron when it becomes an ion. How many electrical charges does the sodium ion have? Is the sodium ion positive or negative?
4. A chlorine atom adds one electron when it becomes a chloride ion. How many electrical charges does a chloride ion have? Is the chloride ion positive or negative?
5. A silicon atom loses four of its electrons. How many electrical charges does the silicon ion have? What kind of charges does it have?

3:4 Physical Properties

Physical properties of a substance depend upon the kind and arrangement of its atoms.

In contrast to chemical properties, which can be determined during chemical reactions, physical properties can be seen and measured. Physical properties may be recognized by one or more of the senses of sight, smell, touch, taste, or hearing. Some physical properties are mass, density, taste, and reflection of light. Chemical properties depend upon the number and arrangement of electrons in the outer shell of an atom; physical properties depend upon the kinds of atoms and their arrangement in a given unit of matter.

Construction of atoms is possible only in the laboratory, or perhaps in outer space.

Hydrogen is the smallest and simplest kind of atom. Its common isotope consists of one proton and one electron. (Figure 3–5.) All other elements may be constructed by adding protons and neutrons to the nucleus, and electrons to the energy shells. Elements increase in mass as protons and neutrons are added. The *atomic number* of an element is the total number of protons in the nucleus of each atom of the element. The *atomic mass number* is the total number of protons and neutrons in the nucleus of each atom of the element. (Table 3–1.) As protons, neutrons, and electrons are added, atoms increase in mass as well as in size. Thus, atoms of great mass are larger than atoms of small mass.

Table 3–1. *Atomic Table of Selected Elements*

Element	*Symbol*	*Atomic Number (protons)*	*Atomic Mass Number (protons + neutrons)*
Aluminum	Al	13	27
Calcium	Ca	20	40
Carbon	C	6	12
Chlorine	Cl	17	35
Helium	He	2	4
Hydrogen	H	1	1
Iron	Fe	26	56
Lead	Pb	82	206
Magnesium	Mg	12	24
Nitrogen	N	7	14
Oxygen	O	8	16
Potassium	K	19	39
Silicon	Si	14	28
Sodium	Na	11	23
Uranium	U	92	238

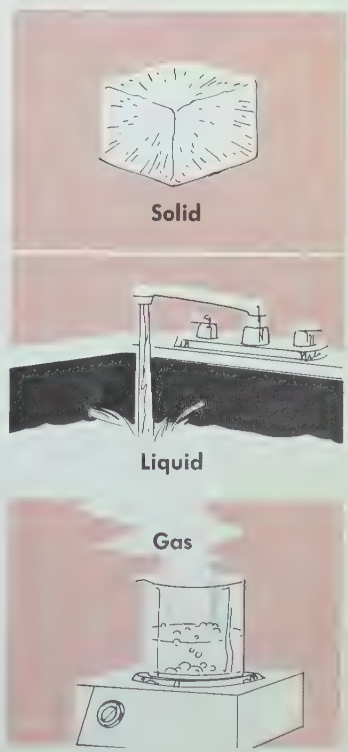
PROBLEMS

1. Refer to Table 3–1. How many electrons does aluminum have? How many neutrons?
2. Uranium 238 is a radioactive element which loses particles from its nucleus and eventually becomes lead 206, a stable element. How many protons are lost during the radioactive decay of ^{238}U? How many neutrons are lost?
3. How many protons must be added to hydrogen to produce helium? How many neutrons must be added?

Physical changes alter only the physical appearance of a substance. Large masses may be divided into smaller units, but each small unit has the same physical properties as the large mass. But on the other hand, chemical changes produce new substances which have different properties. Physical changes depend primarily on the substance itself. Chemical changes depend primarily on the presence of a second substance.

3:5 *States of Matter*

Figure 3-7. The physical state of a substance depends on both pressure and temperature.



Each kind of matter occurs in one of three physical states: solids, liquids, or gas. In *solids*, the atoms or molecules have a rigid, fixed geometric pattern in relation to each other. Each atom or molecule vibrates around a fixed point. But the atom or molecule is held in place by the attraction between its electrons and the nuclei of adjacent atoms or molecules. A solid resists both change in shape and change in volume because its atoms are not free to move. Ice is one example of a solid. Other examples are wood, rocks, and minerals.

In a *liquid*, atoms or molecules are free to move about, but they remain in contact with each other. Liquids resist changes in volume, but they adopt the shape of their containers. Some familiar liquids are water, gasoline, and oil. In a *gas*, atoms cling together in molecules, but the molecules move about independently. Gases expand to fill all available space in a container of any shape or size. Gas molecules move so rapidly that they cannot be held in any fixed position. Gases offer no resistance to change in shape and less resistance than a liquid to change in volume. Differences between solids, liquids, and gases are: (1) distance between the atoms or molecules, and (2) movement of the atoms or molecules. Both distance and movement change with changes in temperature and pressure.

American Airlines

Figure 3-8. Earth's temperature range allows water to exist in a gaseous, liquid, and solid state. In which states does water appear in this scene?

Increases in temperature increase molecular movement, and as molecules become more mobile, a solid becomes a liquid, then a gas.

Physical states for each kind of matter depend upon both the temperature of the matter and the pressure exerted on the matter. Molecules move faster and faster as temperature rises. Falling temperatures slow down the movement of molecules. With rising temperatures, solids become liquids. As molecular velocity increases, the molecules slide past each other and the attraction of adjacent molecules becomes ineffective. Liquids boil and become gases as molecules separate and move about independently. With falling temperatures, molecules slow down, and as they come into contact with each other, the gas becomes a liquid. Liquids become solids as molecules travel too slowly to overcome the attraction of adjacent nuclei. The relationship between temperature and molecular movement remains an area of active research.

Increases in pressure on matter force the molecules into closer and closer contact until, eventually, molecules can vibrate only around a fixed point. Gases become liquids and liquids become solids under applications of pressure. Release of pressure produces the opposite effect. Depending upon the temperature, molecules may be free to move as pressure lessens; solids become liquids and liquids become gases.

EXPERIMENT. Place two large ice cubes in a shallow pan. Place a key or heavy nail on one ice cube and put the pan in the freezing compartment of a refrigerator. Leave the pan in the refrigerator for several hours or overnight. Examine the ice cubes. Where is the key? Explain what has happened.

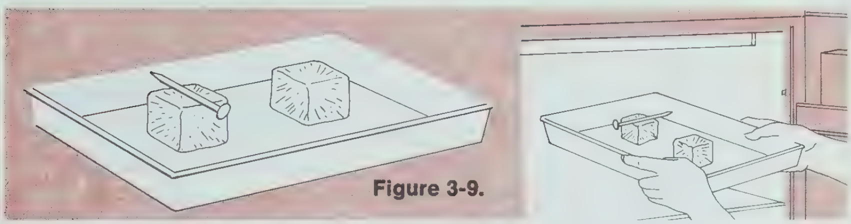


Figure 3-9.

The temperature at which a solid changes to a liquid is called its *melting point.* The temperature at which a liquid becomes a solid is its *freezing point.* Liquids change to gas at the *boiling point.* Because both temperature and pressure may bring about changes in physical states, the melting point, freezing point, and boiling point for each substance varies with pressure. Water freezes at 0°C (32°F) at sea level. A slight increase in pressure raises the freezing point, and melting may occur. Water boils at 100°C (212°F) at sea level. On the top of Pikes Peak (14,000 ft above sea level), air pressure is reduced and water boils at 85°C (185°F).

Temperatures at which changes in state occur are called the melting, boiling, and freezing points. These points vary with pressure.

Water exists as a solid, a liquid, and a gas at the surface of the earth. Its freezing, melting, and boiling points are reached within the range of pressure and temperatures possible in nature. Many substances exist only as solids, liquids, or gases within the range of temperatures that are possible in nature, and some can be changed to a different physical state under laboratory conditions. In the laboratory, it is possible to raise the temperature and pressure to produce conditions that do not exist at the surface of the earth but may resemble or simulate many conditions within the interior. Even in the laboratory, temperatures and pressures that are similar to those of

Present ideas of the physical state of the earth's interior are derived from calculations and laboratory experiments.

the earth's core cannot be reached, but conditions of the mantle may be attained. Scientists depend on laboratory experiments to learn how changes in physical state occur in rock materials.

Scientists also study matter by making models to help them visualize objects they cannot see. Models may be objects, like model cars or airplanes, or drawings and diagrams such as Figure 3–11. Models cannot actually represent particles of matter because the particles are so tiny and always in motion. However, you can learn the number, relative size, and arrangement of particles in different kinds of matter by studying atomic models. Particles in real atoms cling together because of their electrical charges and other factors that are not completely understood. Parts of an atomic model must be supported by wire or some other means, or the model falls apart. Thus, models are never exactly like real atoms.

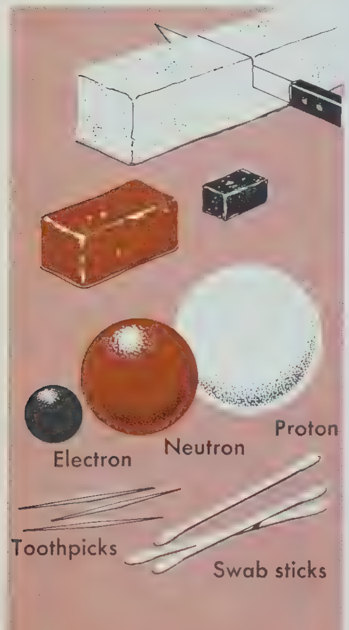


Figure 3-10.

ACTIVITY. To construct models of atoms, you will need one package of round toothpicks or one package of pipe cleaners, one package of swab sticks, and blue, green, and white plasticene modeling clay. Cut the white clay into pieces 1½ in. x 1½ in. x 3 in., the blue clay into pieces 1 in. x 1 in. x 2 in., and the green clay into pieces ½ in. x ½ in. x 1 in. Mold the clay into spheres. The white spheres represent protons, the blue spheres represent neutrons, and the green spheres represent electrons.

You can substitute small styrofoam spheres for the clay spheres. The styrofoam spheres should have diameters of approximately 3 in., 2 in., and 1 in. With felt-tipped pens, color the 2 in. spheres blue and the 1 in. spheres green. You will need 31 white spheres, 31 green spheres, and 23 blue spheres to construct all of the following models.

***The Hydrogen Atom**—Push one end of a toothpick into a white sphere. Attach a green sphere to the other end of the toothpick. Look at Table 3–1. The atomic number of hydrogen is 1 and the atomic mass number of hydrogen is 1. From these values, you can determine that the normal hydrogen atom has one proton, one normal electron, and no neutrons.*

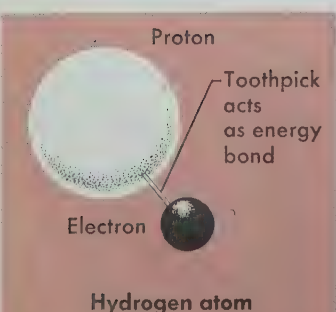


Figure 3-11.

Protons and electrons are not actually held together by a physical bond, such as a toothpick. They are held together by an energy bond. But this model is one way to visualize how hydrogen compares in size and complexity with the atoms of other elements. Even the various spheres do not represent the true size relationships.

__The Helium Atom__—Table 3–1 lists the atomic number and the atomic mass number for helium. From these you can calculate that there are two protons, two neutrons, and two electrons in every atom of helium. To form the nucleus of a helium atom, press two white spheres and two blue spheres together until they stick. Attach a toothpick to each white sphere and put a green sphere on the other end of each toothpick.

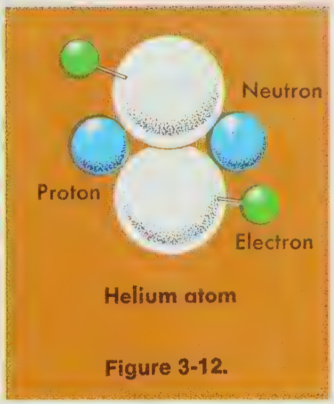


Figure 3-12.

Protons and electrons are presumably held together by opposite electrical charges. The neutrons have no charge, so the electrons do not attract or repel them. Opposite charges attract, and like charges repel. Do you think the protons would cling to one another if there were no neutrons present? If neutrons are neutral, how do they hold the protons?

__The Carbon Atom__—Use six white spheres and six blue spheres. Arrange them in a compact mass so that the colors alternate. Attach two green spheres to two of the white ones by using toothpicks. Attach four green spheres to the remaining four white spheres by using the longer swab sticks.

Compare the diameter of the carbon atom with that of the helium and the hydrogen atoms. Note that the carbon atom has a greater mass than either the hydrogen or the helium atom because it has more protons, electrons, and neutrons. Also notice that the electrons vibrate around the nucleus on two different levels. A maximum of two electrons travel in the first path; a maximum of eight electrons travel in the second path.

Construct two more models. Use seven blue spheres for one carbon atom model and eight blue spheres for another. Do not change the number of protons or electrons.

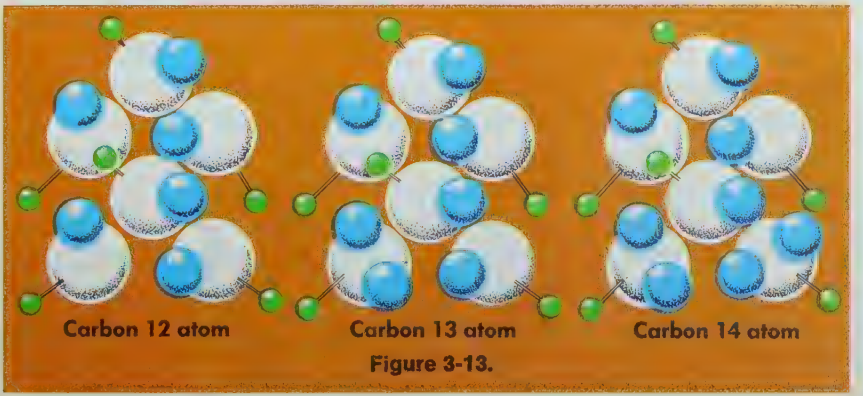


Figure 3-13.

You have now constructed three *isotopes* of the carbon atom. Each atom has similar electrical and chemical properties, but each differs in mass. The different isotopes are recognized by their different *atomic mass numbers*; that is, the sum of particles in the nucleus. If you assume each neutron weighs one gram, you can see that some isotopes weigh more than others.

The first model of carbon you constructed was *carbon 12*, the most abundant stable isotope of carbon. The second model was *carbon 13*, also a stable isotope. The third model was *carbon 14*, the most useful radioactive isotope of carbon. A **radioactive isotope** is unstable and emits particles from the nucleus. Eventually, a radioactive isotope of an element will change to another element. Carbon 14 eventually changes to nitrogen.

Eighty-eight elements have been found in the crust. These elements have joined to form thousands of combinations. The combinations of different elements form new substances called *compounds*. A molecule is the smallest combination of atoms which can exist separately and still retain its composition. A molecule may also be thought of as the smallest combination of atoms that will form a given compound.

Water is made up of two atoms of hydrogen and one atom of oxygen in each of its molecules. Both hydrogen and oxygen are gases found in the air. When they unite in the proper ratio, water is formed. Water is entirely different from either of the gases. Name a few of the differences between water and the elements which compose it.

The Water Molecule—*Construct the oxygen atom first. Omit the eight neutrons in the nucleus in order to simplify construction of the model. Use eight white spheres and eight green spheres. Form the nucleus with the eight white spheres. The electrons vibrate around the nucleus on two different levels or energy shells. Attach two green spheres with toothpicks to two of the white spheres. Attach the remaining six green spheres to the six remaining spheres with swab sticks. Attach the remaining six electrons, three on each side, with space between them for the electrons of the hydrogen atoms.*

Construct two hydrogen atoms like your first model, one proton joined to one electron. Place the oxygen atom between two hydrogen atoms so that electrons from the hydrogen atoms occupy the spaces between the electrons in the oxygen atom. Rotate the three atoms, keeping an electron from the oxygen atom opposite each hydrogen nucleus (proton).

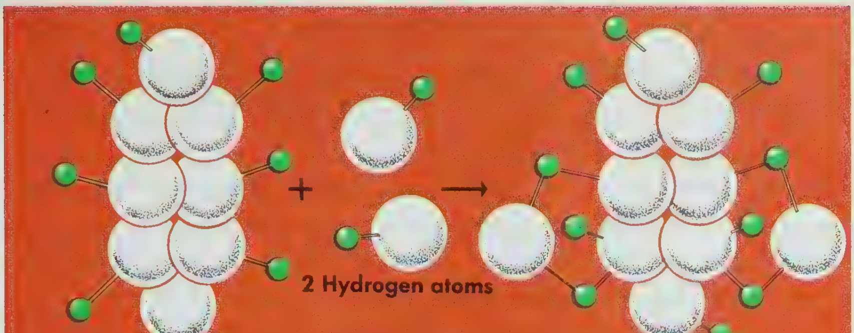


Figure 3-14.

Scientists picture the combining of oxygen and hydrogen to form water in this manner. Oxygen and hydrogen atoms are held together, or *bonded*, because their electrons belong to both nuclei. Demonstrate the bonding between the hydrogen and oxygen until you are sure you understand it. Then fasten toothpicks from the hydrogen electrons to the oxygen nucleus and from the hydrogen nucleus to two of the oxygen electrons. This will give you a more stable model to keep.

Few elements exist in nature in an uncombined form. Future models should be constructed with one sphere representing the entire atom. The models would become too cluttered and complex if some detail were not eliminated.

MAIN IDEAS

1. Matter is anything that has mass and occupies space.
2. Matter exists as mixtures, compounds, or elements. Mixtures may be separated into individual different particles by mechanical processes. Compounds may be separated into their component elements by chemical processes. Elements cannot be separated into simpler components by either chemical or mechanical processes.
3. Atoms are the smallest units in which an element can exist. Atoms are composed of many subatomic particles. Three of the subatomic particles are protons, electrons, and neutrons. Protons have positive electrical charges; electrons have negative electrical charges; neutrons have no electrical charge.
4. It is believed that negatively charged electrons are attracted to the nucleus of an atom by the positive charges of the protons in the nucleus.

5. Atoms of one element may combine with atoms of different elements to form compounds. The smallest unit of a compound is a molecule.
6. Each atom (except normal hydrogen) has a nucleus composed of protons and neutrons surrounded by a cloud of electrons which vibrate around the nucleus at varying distances. The number of electrons equals the number of protons in an atom. These numbers are constant for atoms of a given element.
7. Number of neutrons in the nucleus of an atom of a given element may vary. Therefore, atoms of the same element may differ from each other in their mass. Isotopes are atoms of the same element that have different masses. They have different numbers of neutrons in their nuclei.
8. Atoms are ordinarily stable, or electrically neutral, because numbers of protons and electrons are equal. Ions are unstable particles formed when atoms lose or gain electrons. Ions that lose electrons have positive charges equal to the number of electrons that have been lost. Ions that gain electrons have negative charges equal to the number of electrons that have been gained. Ions with opposite charges join to form stable compounds in which numbers of protons are balanced by numbers of electrons present.
9. Chemical properties determine the behavior of an atom in the presence of different kinds of atoms. All atoms of a given element have the same chemical properties and exhibit the same kind of behavior.
10. Elements differ from each other in mass as the number of protons and neutrons in the nucleus increases. The atomic mass number of an element indicates the total number of neutrons and protons present in each of its atoms. The atomic number indicates the number of protons present in the nucleus of each atom of a given element.
11. Matter occurs in one of three physical states: solid, liquid, or gas. In the solid state, atoms vibrate about a point but have fixed positions. Solids resist changes in volume and changes in shape. In the liquid state, atoms move about more freely but remain in contact. Liquids resist changes in volume but have no resistance to changes in shape. In a gas, molecules move rapidly and independently and have no resistance to change in shape and little resistance to change in volume.

12. Substances may change from one physical state to another if changes in temperature and/or pressure occur. If pressure remains constant, an increased temperature tends to allow molecules to move about more readily and the substance may go from the solid to the liquid to the gaseous state. If temperature remains at a certain point, increased pressure slows the movement of molecules and gases may become liquids, and liquids may become solids.
13. Models constructed to represent atoms cannot reproduce their actual condition or form, but they assist in an understanding of atomic structure.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

atomic number	isotopes
boiling point	matter
electron cloud	mixtures
electrons	models
elements	molecules
energy levels	neutrons
helium	protons
hydrogen	stable
ions	subatomic particles

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Matter has the property of inertia.
2. Matter of the earth consists of rocks, minerals, water, air, and living things.
3. Mixtures are the same as compounds.
4. Compounds may be separated into elements by crushing.
5. No two elements have the same number of protons.
6. Electrons contribute the greatest mass to the atom.
7. Protons have no electrical charge.

8. Electrons have a negative electrical charge.
9. Protons and electrons form the nucleus of an atom.
10. Ions have an electrical charge.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Unique combinations of the subatomic particles of matter are called (*elements, mixtures, neutrons*).
2. The smallest unit with the characteristics of a given substance is a(n) (*molecule, atom, electron*).
3. The smallest unit with the characteristics of an element is a(n) (*molecule, atom, neutron*).
4. When atoms lose or gain electrons, they become (*ions, neutrons, compounds*).
5. Physical properties include (*density, solubility, electrical charges*).
6. The physical state of matter depends on its (*temperature and pressure, solubility, chemical properties*).
7. Most substances in nature are (*elements, compounds, mixtures*).
8. Rearrangement of atoms occurs during (*filtering, chemical reactions, grinding*).
9. The mass of a proton is (*less than, greater than, the same as*) the mass of an electron.
10. Positive ions unite with negative ions to form (*mixtures, compounds, elements*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Three subatomic particles of matter are the __?__, __?__, and __?__.
2. An element is determined by the number of __?__ in its atom.
3. Two or more elements combine to form a(n) __?__.
4. Neutrons contribute __?__ to the atom.

5. Atoms are balanced and have no __?__.
6. Physical state of a substance depends on its __?__ and __?__.
7. Liquids may become __?__ if the pressure is constant and the temperature increases.
8. Chemical reactions involve the rearrangement of __?__.
9. A compound may be separated into simpler units by __?__.
10. Mixtures may be separated into their individual components by __?__.

D. How and Why

1. What is the main difference between a mixture and a compound?
2. What is the difference between an ion and an atom of a given element?
3. What do neutrons contribute to an atom?
4. Why is a compound called a balanced or stable unit of matter?
5. What is the effect of temperature on the physical state?
6. Would hammering on a piece of metal change its chemical properties? Explain.
7. Do the chemical characteristics of a solid change when it becomes a liquid?
8. What kind of property is mass?
9. How does pressure affect a substance if the temperature remains constant?
10. Discuss what might happen to a substance if both temperature and pressure increase.

INVESTIGATIONS

1. Discuss the origin of the term "X ray." How was the X ray discovered?
2. Report on the work of Madam Marie Curie and her husband Pierre in their study of radioactive materials.
3. Discuss some milestones in the development of the use of atomic energy.

INTERESTING READING

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* Well-illustrated material.

Matter of the Lithosphere

The crust of the earth consists of matter in the form of rocks and minerals. Recall that all matter consists of protons, neutrons, and electrons combined to form atoms. Matter made of only one kind of atom is an element. Elements may be combined to form chemical compounds, and chemical compounds or elements may be mingled in various proportions to form mixtures. In the earth's crust, single elements and chemical compounds occur as minerals. Single minerals and mixtures of minerals occur as rocks. If you examine the ground that lies beneath you everywhere, you may find boulders in some places. But more often you will find soil. Boulders and soil appear to be different from one another, but both of them have come from the original rock materials of the crust.

4:1 *Minerals*

The **lithosphere** (lith′a sfir) is the outer crust of the earth. The Greek word *lithos* means rock or stone. Thus, the word lithosphere means that the earth's sphere is made of rock. Approximately 2,000 minerals have been recognized in the lithosphere, but only 88 elements* have been found. Eight of the 88 elements make up 98.58 percent of the matter of the crust. (Table 4–1.) The other 80 elements constitute only 1.42 percent of the lithosphere.

Of the 2,000 known minerals, only 12 are abundant enough to be essential to the earth's crust. These twelve minerals are called *rock-formers* because they make up the bulk of the lithosphere. If all of the other minerals were absent from the

Of the 2,000 known minerals, only 12 minerals are essential rock-formers.

* More than 100 elements have been recognized by chemists, but only 88 occur in the earth's crust.

crust, continents would look the same and have approximately the same characteristics. Many of the uncommon minerals are important to industry, to culture, and to economic welfare. But they are not abundant components of the lithosphere.

Table 4–1. *Abundant Elements of the Lithosphere*

Element	*Symbol*	*Percentage by Weight*
Oxygen	O	46.60
Silicon	Si	27.72
Aluminum	Al	8.13
Iron	Fe	5.00
Calcium	Ca	3.63
Sodium	Na	2.82
Potassium	K	2.59
Magnesium	Mg	2.09

Rocks are mixtures; minerals are compounds or elements.

Minerals are either elements or chemical compounds that are: (1) inorganic, (2) formed in nature, (3) solid, (4) of a definite internal atomic pattern, (5) of a definite constant chemical composition within certain well-defined limits.

1. *Minerals are inorganic.* This means that minerals consist of matter other than animal or vegetable material. Minerals are not alive and the processes by which they form are not life processes. Some difficulty arises because marine animals, such as corals and mollusks (mahl′usks), use certain minerals extracted from seawater to make their shells. Shells consist of the same chemical substances that are called minerals. However, because the shell was formed by a living animal, the shell material is not called a mineral.

2. *Minerals are formed in nature.* Man has learned to manufacture many artificial gems and other substances that have exactly the same characteristics as minerals formed by natural processes. These artificial substances are not properly classed as minerals. Gems found in nature have greater value than those made by man.

3. *Minerals are solids.* In Section 3:5, you read that a solid resists a change in shape or a change in volume because its atoms are arranged in fixed positions. The size and arrangement of its atoms determine the outward shape of a solid. Solids have geometric patterns, all of which belong to one of six crystal systems. (Figure 4–12.)

4. *Minerals have definite internal atomic patterns.* The atoms of each mineral are arranged in a characteristic pattern. Because a mineral is a solid, its atomic arrangement remains constant. If a mineral melts or dissolves in a liquid, its atoms no longer have a rigid pattern and it is no longer considered to be a mineral. However, the same atoms are present in the liquid that were present in the mineral.

University of Houston

Figure 4-1. Tourmaline crystal.

The internal pattern of atoms in a mineral may be so small that it can be observed only by means of X-ray diffraction. Or the atomic pattern may be repeated over and over until it is large enough to be seen by the naked eye. The repetition of the same combination of atoms is similar to the repetition of a pattern in tile or linoleum. If the atomic pattern can be recognized, the resulting shape is called a **crystal**. A given mineral always occurs in the same general crystal shape. Museums frequently display large crystals that have formed in nature. Such crystals show the internal atomic pattern of the mineral.

University of Houston

Figure 4-2. Pyrite crystals.

Large crystals are uncommon because sometimes, when crystals start to form, they interfere with each other. Then, instead of growing into large, recognizable crystals, the minerals occur as masses. Under a microscope, the crystal form often can be recognized. Occasionally, however, the crystals are so small they can be seen only by means of X-ray diffraction.

5. *Minerals have specific chemical compositions.* A mineral always is composed of the same kind of atoms, in the same proportions, arranged in the same way. For example, every specimen of *quartz* (kwawrts), a very common mineral, has atoms in the ratio of two atoms of oxygen to one atom of silicon. Actually, a specimen of quartz contains billions of oxygen atoms and billions of silicon atoms. But the ratio of these two kinds of atoms is always two oxygen atoms to one silicon atom. Chemists use a kind of shorthand to indicate the composition of a chemical substance. Minerals are either elements or chemical compounds, so *symbols* or *formulas* are used to indicate the composition of a mineral. For quartz, the formula is SiO_2. Tables 4–4 and 4–5 give the symbols or formulas for several minerals.

Minerals always have the same kind of atoms arranged in the same way.

Geologists define a mineral as having a specific chemical composition within certain, well-defined limits. You have seen what is meant by a specific chemical composition. But what is meant by well-defined limits? In nature, one kind of atom may be so similiar to another kind of atom that the two can substitute for one another. However, the ions must be of the same radius and

Substitution of one atom for another in an atomic pattern may occur only for ions of the same radius and with the same electrical charges.

have the same electrical charges to be exchangeable. Substitution may occur up to a certain point without changing the mineral characteristics. Picture atoms as building blocks and the atomic pattern as a building made of these blocks. As long as the blocks were the same shape and size, you could substitute a blue block for a white block without disturbing the structure of the building. You would have the same pattern of blocks and a predominantly white building unless you kept substituting blue blocks for white ones. Eventually, the building would be blue if you exchanged all of the blocks.

Amount of substitution that may occur without having a mineral name change depends upon arbitrary decisions by mineralogists who study mineral characteristics.

Substitution of one element for another element takes place in some minerals. If substitution is carried to a point where the mineral color or another characteristic is changed, then the combination is given a new name. The point at which the name is changed is set by *mineralogists*, scientists who specialize in the study of minerals.

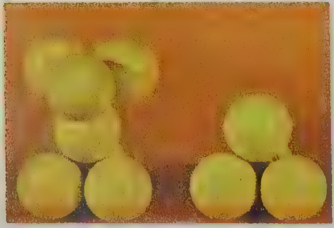
Review the five points of the definition of a mineral. Note that all five conditions must be met if a substance is to be called a mineral.

Silicates are the most common minerals, carbonates are next, and oxides are least common. All of these minerals are combinations of one or more of the most abundant elements and some other elements which may or may not be among the eight most abundant elements.

Minerals that contain mainly the eight abundant elements listed in Table 4–1 are common. Minerals that contain as major constituents the other 80 elements found in the earth's crust are rare. The largest group of minerals are called *silicates* (sil′i kaets). **Silicates** are combinations of silicon (Si) and oxygen (O) and some other elements. Because silicates are present in most rocks, they are called rock-formers. In the earth's crust, 87 percent of the minerals are silicates.

Combinations of carbon and oxygen and some other elements such as calcium, magnesium, or iron are called *carbonates* (kahr′ba naets). **Carbonates** are next in abundance after the silicates. *Oxides* (ahk′sieds) are also important minerals, but are much less common than either silicates or carbonates. **Oxides** are combinations of oxygen and some other element.

Figure 4-3. The tetrahedron is the basic unit of all silicate structure. Left: double tetrahedral structure (Si_2O_7). Right: single tetrahedral structure (SiO_4).



Ward's Natural Science Establishment, Inc.

Figure 4-4. In the SiO_4 tetrahedron, the four oxygen ions are situated on the four corners of a tetrahedron with the silicon ion at the center.

ACTIVITY. To construct some mineral models, you will need four times as much white plasticene modeling clay as the other three colors. Cut the clay into pieces as follows: white—1½ in. x 1½ in. x 3 in.; blue—1 in. x 1 in. x 2 in.; green—½ in. x ½ in. x 1 in.; red—¼ in. x ¼ in. x ½ in. Roll the plasticene into spheres. White spheres represent negatively charged ions; the other spheres represent positively charged ions of different diameters. First use a red sphere as the center of an atomic unit. Arrange white spheres around the red one so that each white sphere is in contact with the red sphere and with two other white ones. Place this unit flat on the table. Using a ruler, place it tangent *(tan′jent) to or touching two white spheres and draw a line. (Figure 4–5.) Continue drawing similar lines for each two white spheres. As you look down on the outline of the model, what is its shape?*

Repeat the model construction, but this time use a blue sphere as the center ion. Make a third model using a green sphere as the center ion surrounded by white spheres. How does the diameter of the center ion affect the number of ions which surround it? What controls the arrangement and size of the crystals of a mineral?

In constructing the following model, let the white sphere represent the complete atom. Arrange four white spheres in a pyramid. This geometric form is called a tetrahedron (te tra hee′dron). It can be turned in any direction without changing the shape or size of the unit. Make four tetrahedra and arrange them in a chain. Remove one corner atom from one tetrahedron. Let the corner atom of another tetrahedron take its place. (Figure 4–6.) Continue this procedure until all four tetrahedra are joined in a chain. How many atoms did you remove to make a continuous chain? How many atoms are left?

Construct four more tetrahedra. Now make a double chain in which two tetrahedra are joined at two corners. (Figure 4–7b.) How many atoms did you remove in making the double chain? How many remain?

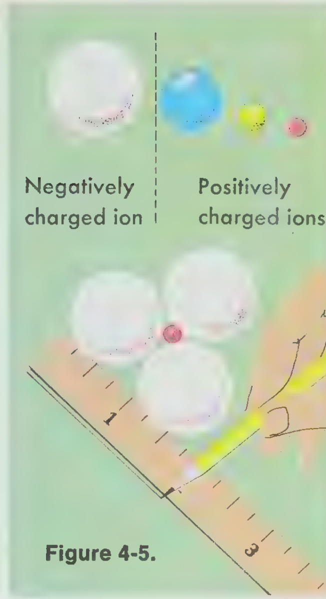


Figure 4-5.

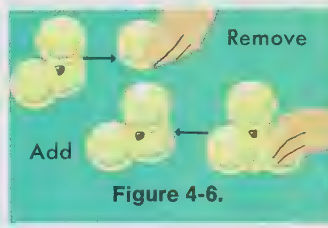


Figure 4-6.

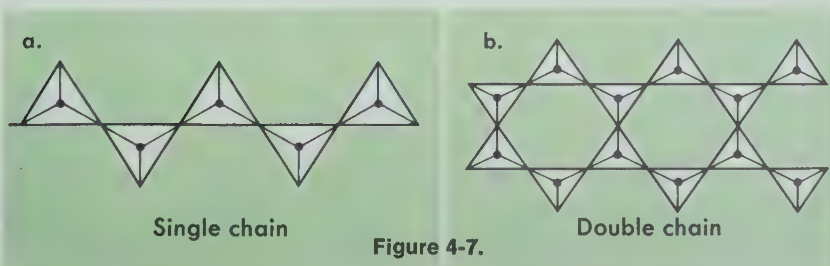


Figure 4-7.

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Figure 4-8. The SiO_4 tetrahedrons may join by sharing oxygen atoms with neighboring tetrahedra. Left: single chain structure of pyroxene. Right: double chain of amphibole.

The single and double chains are the basic units for two common mineral families, the *pyroxenes* (pie rahk'seens) and the *amphiboles* (am'fi bohls). Pyroxenes contain the single chains; amphiboles contain the double chains. Pyroxene minerals *cleave* (kleev), or break along smooth plane surfaces, parallel to the single chain. Amphiboles cleave parallel to the double chain.

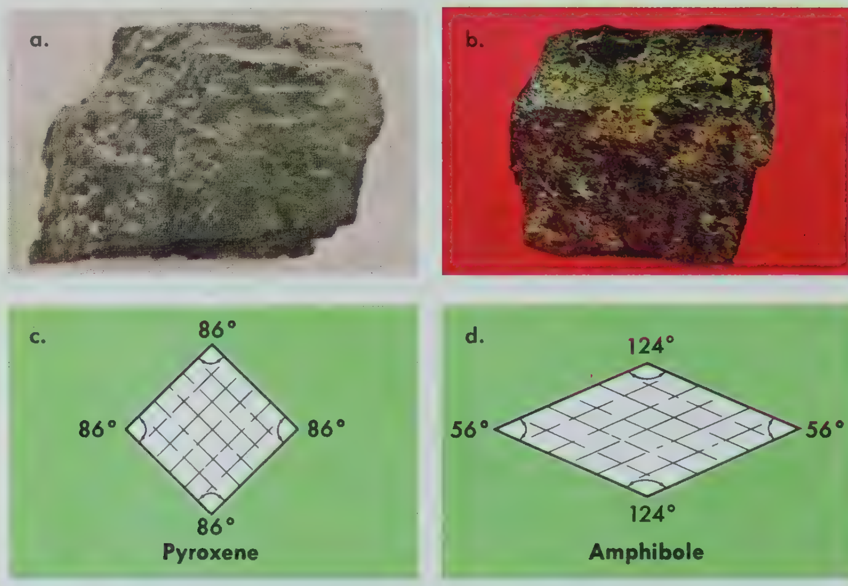

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Figure 4-9. Cleavages occur along directions of weak bonding in the atomic structure of the minerals pyroxene (a.) and amphibole (b.).

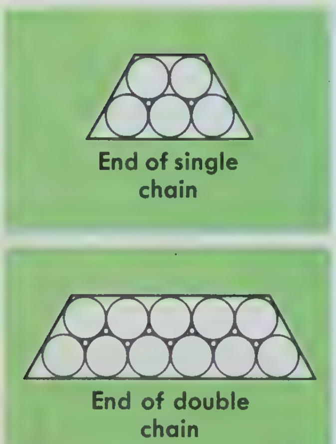


Figure 4-10.

With the help of another student, trace the outline of the base of each of your chains. Measure the angles. What measurement might be a clue to help you distinguish between amphibole and pyroxene minerals?

One of the earliest discoveries about minerals was that the angle between *crystal faces* (the flat surfaces which join at well defined angles) is always the same number of degrees regardless of the size of the mineral crystal.

ACTIVITY: Use two or three large crystals of quartz or calcite (kal'siet). Count the sides of the minerals. Trace the outline of a crystal on a sheet of paper. Measure the angles bounded by the crystal faces. Compare your results with the results of several other students. What is the measurement range? Find the average of the measurements determined by five students.

Figure 4-11.

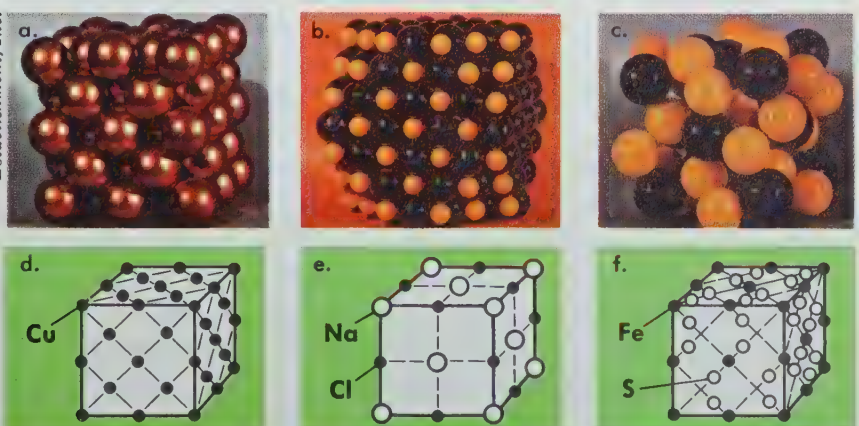
ACTIVITY. *Look at the diagrams showing the six crystal systems. (Figure 4–12.) Measure the length of each side of the cube. How do these lengths compare? Measure the length of each side of the* tetragonal *(te trag′an l)* system. *How do these lengths compare? Make similar measurements for each system, and keep a record of them.*

Using your largest plasticene spheres for corners and toothpicks for edges, construct models of each of the first four crystal systems. Use a protractor to be sure that the angles are properly measured at the corners. The angles should be 90°, except for the hexagonal system, in which the angles are 60°.

On your model of the cubic system, *make two diagonals across the top of the cube, using thread. Then make diagonals across the bottom. Place a sphere on the top and bottom of the cube where the diagonals cross. Connect these spheres with a toothpick. The central toothpick is the* axis *of the cube. It is parallel to the sides, and the same length as the sides. Continue this construction of axes for the other sides of the cube. When you have constructed the three axes, measure them, and determine the angles made by the intersecting axes. Write a definition for a cube, using the information you have determined about the axes and the sides.*

Construct the axes for the tetragonal, orthorhombic *(awr tha rahm′bik), and* hexagonal *(hek sag′an l) systems. The longest axis is called the* c axis; *the one pointing toward you is the* a axis, *and the other axis is the* b axis. *Define each of the four crystal systems in terms of the* a, b, *and* c *axes, and indicate their relationship to the sides.*

Figure 4-13. Models of copper (a.), halite (b.), and pyrite (c.) illustrate various arrangements of atoms, all of which are in the cubic system. Sketches of copper (d.), halite (e.), and pyrite (f.) illustrate the basic units of these minerals which are repeated numerous times to form visible crystals.



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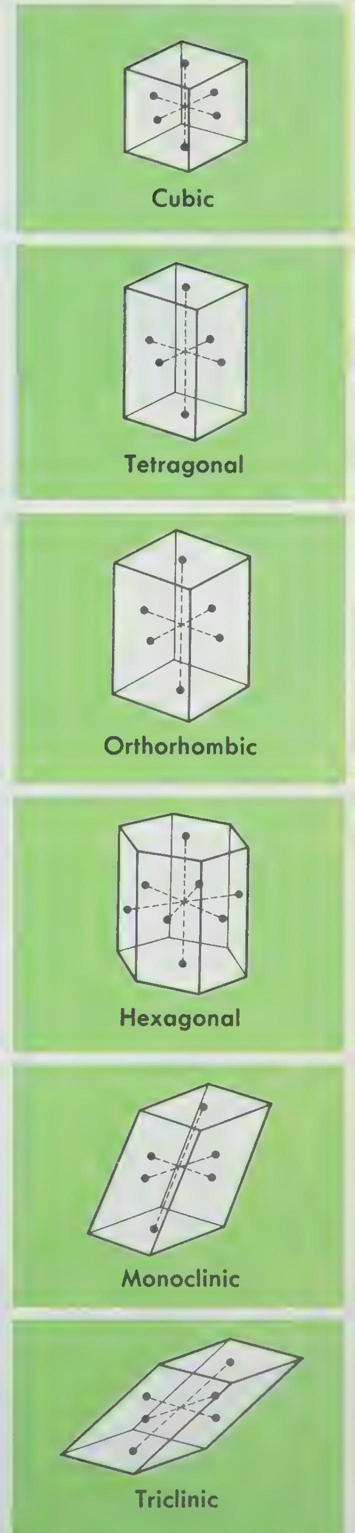

Figure 4-12.

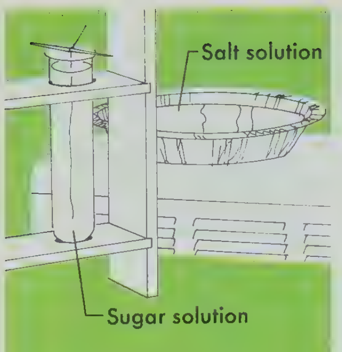

Figure 4-14.

EXPERIMENT. Dissolve 1 cup of sugar in ½ cup of boiling water. When all of the sugar has dissolved, fill a test tube with the solution. Set the solution in a test tube rack and place a toothpick across the top of the tube. Suspend a thread from the toothpick and carefully lower the thread into the sugar solution so it does not touch the sides or bottom of the test tube. (Figure 4–14.) Let the solution stand for 24 hours. Examine the thread. What has happened? Look at the material under a high-powered magnifying glass. Explain what has occurred.

Dissolve 1 cup of salt in ½ cup of warm water or until no more will go into solution. The solution is saturated *when salt remains in the bottom of the cup even after vigorous stirring. Pour the saturated solution of salt water into a shallow dish and place it in the sun or near a warm radiator. Record what happens. Compare the results of this experiment with your experiment on sugar crystals. Is the process of crystallization exactly the same?*

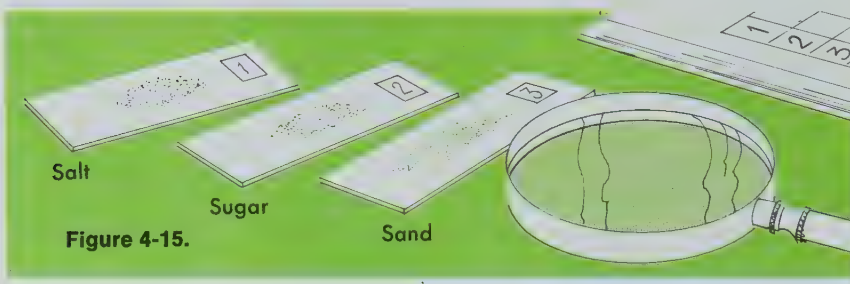

Figure 4-15.

EXPERIMENT. Use salt crystals from the previous experiment or place a few grains of salt on a clean glass slide. Place crystals of sugar on another slide, and a few grains of sand on a third slide. Examine each slide under a microscope or strong magnifying glass. Note the differences and similarities among the crystals. Number the slides, and put the numbers in your notebook with the descriptions and the drawings of the observed grains.

4:2 *Identification of Minerals*

Minerals are recognized by physical properties which include those characteristics that can be seen and measured or recognized by one of the five senses.

Minerals are identified by their physical properties. You can learn to recognize particular minerals through their appearance, smell, taste, feel, or sound when tapped. Appearance and feel are the most useful physical properties, but taste and smell are important clues to the identity of some minerals.

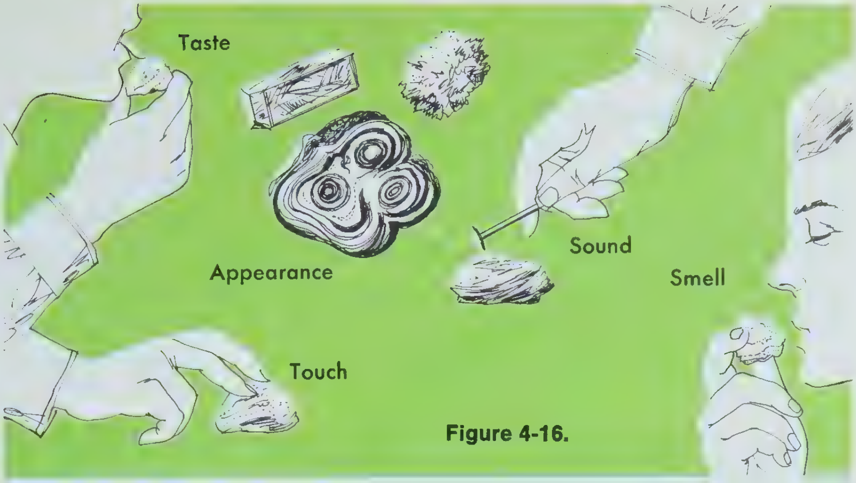

Figure 4-16.

ACTIVITY. You will be given mineral samples to examine with and without a microscope. List all of the characteristics that you think would be useful in recognizing the minerals. Base your answers on principles developed from model construction and crystal growing.

The appearance of a mineral is its most useful characteristic for identification. You can learn to recognize minerals just as you learn to recognize your friends, by the way they look. Physical properties by which you can recognize most minerals include crystal form, hardness, luster, cleavage and fracture, streak, and specific gravity or heft. The following discussion leads you through a series of tests which pinpoint the identifying characteristics of a number of common minerals.

Physical properties of minerals include crystal form, hardness, luster, cleavage or fracture, streak, and specific gravity.

Physical properties of thousands of minerals have been cataloged by mineralogists and arranged in charts similar to Tables 4–4 and 4–5. To identify an unknown mineral specimen, ask yourself the following eight questions:

1. Is the mineral shiny? *Luster* refers to the way light is reflected from a mineral. If a mineral shines like a highly polished surface, it has **metallic luster.** If it is dull and does not reflect light, or if it allows light to pass through in the way window glass does, the mineral has **nonmetallic luster.** Nonmetallic luster may be described as dull, pearly, silky, glassy, or sparkling. Metallic luster is common among minerals that contain one of the metals, such as gold, silver, or lead. If the unknown mineral is shiny, turn to the first part of the chart where minerals with metallic luster are described. If the unknown mineral is not shiny, turn to the descriptions of minerals with nonmetallic luster.

Minerals that reflect light as though from a polished surface have metallic luster.

Streak, the color of the powdered mineral, is an important characteristic for minerals below 5 in hardness.

2. Can you streak the mineral? Rub the unknown mineral sample on a piece of unglazed porcelain, such as the back of a porcelain tile or a *streak plate*. Does the rubbing cause a streak? **Streak** is the color of the powdered mineral. Streak is a very important property in minerals that are softer than the porcelain streak plate and an especially useful aid for identifying metallic minerals. If no streak appears, the mineral is said to have a colorless or white streak. Locate the color of the streak of your unknown mineral in the mineral chart.

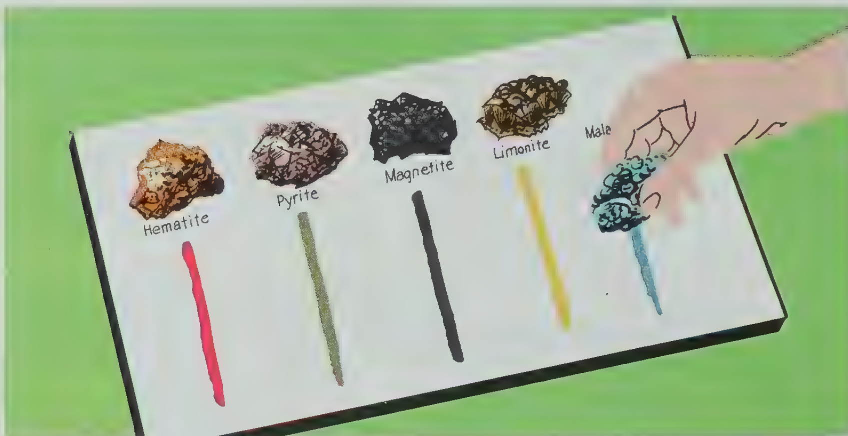

Figure 4-17. Color of the streak may be a very different color from the mineral. Only the mineral, not the matrix, should be rubbed on the streak plate.

3. How hard is the mineral? Hardness is one of the most useful means for identifying minerals. **Hardness** is the resistance of a mineral to being scratched. A harder mineral always scratches a softer mineral. Fredrich Mohs, a German mineralogist, devised a scale of hardness which assigns numbers to ten reference minerals in the order of increasing hardness. (Table 4–2.) Each mineral will scratch any mineral which has a lower number on the Mohs scale. You can determine the hardness of an unknown mineral sample by scratching its edge against the surface of each mineral in a set of hardness minerals. Minerals in a set of hardness minerals are assigned numbers corresponding to the Mohs scale. The unknown has the hardness of a mineral which it cannot scratch, and by which it cannot be scratched. The unknown mineral is softer than a mineral which scratches it; the unknown mineral is harder than a mineral which it can scratch.

Figure 4-18. Only fresh surfaces of a mineral should be used to test its hardness.

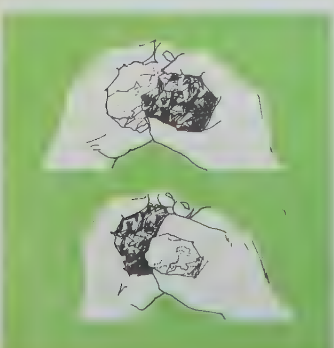

Table 4–2. *MOHS SCALE OF HARDNESS*

1—Talc	6—Orthoclase
2—Gypsum	7—Quartz
3—Calcite	8—Topaz
4—Fluorite	9—Corundum
5—Apatite	10—Diamond

If you are collecting rocks and minerals on a field trip, the Mohs set of minerals is seldom available. The scale in Table 4–3, called the *field scale*, is convenient. However, the hardness determinations are not quite as exact as comparisons with a Mohs set of hardness minerals.

Table 4–3. *FIELD SCALE OF HARDNESS*

1—Soft, greasy, flakes on fingers
2—Scratched by fingernail
3—Cuts easily with knife or nail, or scratched by penny
4—Scratched easily by knife
5—Scratched by knife, but with difficulty
6—Scratched by steel file or piece of glass
7—Scratches steel file
8—Scratches quartz
No approximations above 8

4. What is the shape of the mineral? **Shape** refers to the geometric pattern or crystal habit characteristic of certain minerals. If your unknown mineral has a recognizable geometric shape, the atomic pattern has been repeated over and over until it is large enough to be seen without the aid of a microscope. Recall that solids exist in one of six crystal systems, and compare your unknown mineral with the models of crystal systems and the drawings in Figure 4–19. If the unknown specimen has no recognizable crystal form, it may be *massive*. Examine the specimen with a magnifying glass to see whether you can recognize its form. Massive specimens may be described by terms that suggest their appearance, such as compact, fibrous, or granular. *Amorphous* (a mawr′fus) minerals, which properly should be called *mineraloids* (min′ra lawids), have no recognizable crystal form, even when examined by X-ray diffraction. Mineraloids are often glassy, smooth, and compact.

Minerals may occur as crystalline or massive solids.

Amorphous substances do not have a recognizable internal atomic structure and are properly called mineraloids.

Figure 4-19. Crystal habits of several minerals.

Octahedral means that the solid has eight plane faces with all angles less than right angles. **Rhombohedral** means that the solid is a six-sided figure with angles greater than or less than right angles.

5. *Does the mineral have any broken surfaces?* The way in which a mineral breaks is described by its *cleavage* and its *fracture* (frak′chur). Minerals that break along smooth flat planes are said to **cleave.** Cleavage planes may meet in angles that bound a geometric form. Or cleavage may occur in only one or two directions. Basal cleavage is cleavage parallel to the base of a crystal. Cleavage may be cubic, octahedral (ok ta hee′dral), rhombohedral (rahm boh hee′dral), or any of the other forms in which solids occur. Recall that in an Activity in Section 4:1 you outlined the cleavage angles for pyroxenes and amphiboles. You also found these angles important means of distinguishing between the two mineral families. **Fracture** is breakage along an irregular surface which may be described as rough, conchoidal (kan kawid′l) (curved), or hackly (thin jagged points jutting upward).

6. *What is the color of the mineral?* Color is important for the identification of only a few minerals. Color of most minerals varies with the impurities included in the mineral when it crystallized or with the amount of surface tarnish. A few minerals have constant color and may be recognized by this property.

Figure 4-20. Chalcopyrite.

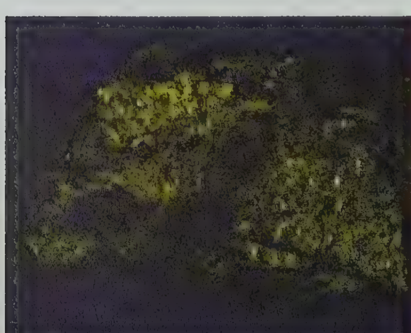

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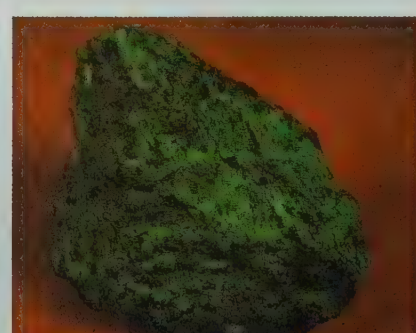
Figure 4-21. Malachite.



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Pyrite, gold, and chalcopyrite (kal ka pier iet) are always metallic yellow. The copper mineral azurite (azh'a riet) is a deep blue. For most minerals, streak is a more reliable clue than the color of the mineral in mass.

7. Is the mineral heavy? **Specific gravity** refers to the ratio of the mass of a mineral to the mass of an equal volume of water. (Section 2:4.) Specific gravity is useful in the recognition of very heavy minerals, such as galena. In general, minerals with specific gravities above 4 usually contain metals. The *heft* or relative weight can be judged by picking up the mineral. Specific gravity is not a useful characteristic for identification of nonmetallic minerals because their specific gravities are too similar. Specific gravity is useful, however, in some laboratory identifications where measurements are very precise.

Minerals which contain metals often have a high specific gravity. Lead and iron add mass to their minerals.

8. Does the mineral have some unique characteristics? Be sure to check the column labeled Other Properties in Tables 4–4 and 4–5. Here you will find unusual features that may be helpful in recognizing certain minerals. Some minerals can be identified by distinctive properties, such as *taste* for halite, *odor* for sulfur, and the bell-like *ringing* of jade when tapped. The properties in this column will help you to distinguish among several mineral descriptions that otherwise seem to fit your unknown mineral.

ACTIVITY. Identify some of the minerals you were given for inspection and the minerals you have acquired. First ask yourself the eight questions discussed in this section. Follow all of the suggestions given and find each unknown in Tables 4–4 or 4–5. Put a small square of white paint on your own specimen. The room specimen will have been labeled with a number. After you have used all of the tests, check with the teacher to be sure of your identification. Then number your minerals as the room minerals are numbered. In your notebook, write the numbers and the name of the mineral with the number. For your tests, you will need a powerful magnifying glass or microscope, unglazed porcelain (tile or streak plate), 15 percent hydrochloric acid, and a set of hardness minerals. Check for hardness with a nail, a penny, and a piece of glass and prove your conclusion on the hardness minerals listed in Table 4–3. In this way you will become familiar with the field scale which will be most useful to you in your own collecting. You may want to arrange the minerals in a display to exhibit some particular characteristic of mineral formation.

Figure 4-22.

Table 4-4. *Minerals With Metallic Luster*

Mineral	*Color*	*Streak*	*Hardness*	*Specific Gravity*	*Shape*	*Breakage Pattern*	*Other Properties*
Graphite	Black to gray	Black	1-2	2.3	Hexagonal	Perfect basal cleavage	Greasy, soft, smudges fingers
Hematite (specular) Fe_2O_3	Silver gray	Reddish brown	6	5.3	Hexagonal massive	Uneven fracture, no cleavage	Earthy, brittle, source of iron
Pyrite FeS_2	Light brassy yellow	Greenish black	6.5	5.0	Cubic, massive	Conchoidal fracture	Alters to limonite, "fool's gold"
Magnetite Fe_3O_4	Black	Black	6	5.2	Cubic, granular	Conchoidal fracture	Naturally magnetic, source of iron
Galena PbS	Gray	Gray	2.5	7.5	Cubic, massive, granular, fibrous	Cubic cleavage, even fracture (rare)	Source of lead, often with sphalerite (zinc-containing mineral)
Bornite Cu_5FeS_4	Bronze, yellow, tarnishes to dark blue, purple	Grayish black	3	5.0	Cubic, massive, compact	Uneven fracture, poor octahedral cleavage	Purple-tarnished surface looks like hard coal and gives rise to name "peacock ore"
Copper Cu	Copper red, tarnishes to black	Copper red	3	8.1	Cubic, wire-like form	Hackly fracture	Malleable and ductile

Figure 4-23. Graphite Schist.

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Figure 4-24. Pyrite (massive).

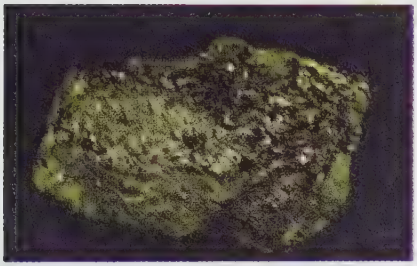

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Figure 4-25. Magnetite (massive).

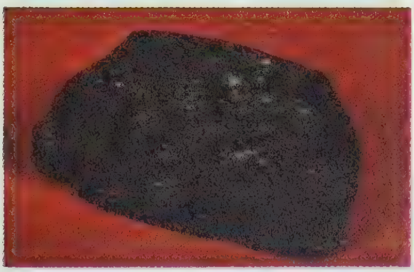

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Figure 4-26. Galena.

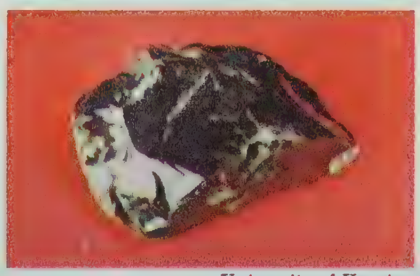

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Table 4-5. *Minerals With Nonmetallic Luster*

Mineral	*Color*	*Streak*	*Hardness*	*Specific Gravity*	*Shape*	*Breakage Pattern*	*Other Properties*
Talc $Mg_3(OH)_2Si_4O_{10}$	White, greenish	White	1	2.8	Monoclinic, massive, granular	Cleavage in one direction, thin sheets, uneven fracture	Pearly, soapy, easily cut
Gypsum $CaSO_4 \cdot 2H_2O$	White, gray, brown	White	2	2.3	Monoclinic, massive	Basal cleavage, fibrous fracture	Pearly, silky, dull, glassy
Calcite $CaCO_3$	White (pure), varied (impure)	White	3	2.7	Hexagonal, massive	Rhombohedral cleavage, conchoidal fracture	Dull or pearly, releases CO_2 when HCl is added
Fluorite CaF_2	White, green, yellow, purple, red, blue	Colorless	4	3-3.3	Cubic, octahedral	Octahedral cleavage, conchoidal fracture	Glassy to dull, brittle, fluorescent, phosphorescent, twin crystals common
Apatite $Ca_5(Cl,F)(PO_4)_3$	White, yellow, brown, blue, green	White	5	3.2	Hexagonal, massive	Conchoidal fracture	Glassy to dull, brittle, granular
Feldspar (orthoclase) $KAlSi_3O_8$	White to gray, red, green (rare)	Colorless	6	2.5	Monoclinic, massive	Two cleavage planes meet at 90° angles, conchoidal fracture	Common in igneous rock
Feldspar (plagioclase) $(Na,Ca)(Al,Si)AlSi_2O_8$	Gray, green, white	Colorless	6	2.5	Monoclinic, massive	Two cleavage planes meet at 90° angles, conchoidal fracture	Fine parallel lines on cleavage surface distinguish feldspar (plagioclase) from feldspar (orthoclase)
*Garnet (pyrope) $Mg_3Al_2Si_3O_{12}$	Deep yellow-red	Colorless	7.5	3.5	Cubic	Uneven to conchoidal fracture, no cleavage	Glassy, very common mineral, pyrope used in garnet sandpaper

*Valuable as gems or semi-precious stones.

Figure 4-27. Talc.

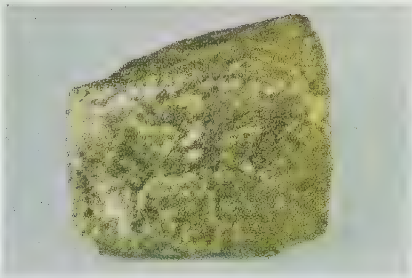

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Figure 4-28. Gypsum.

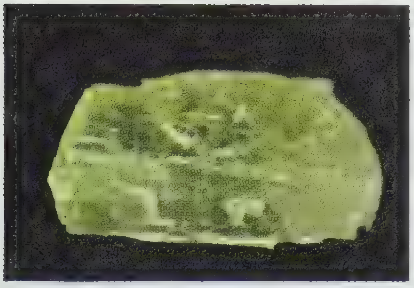

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Figure 4-29. Fluorite.

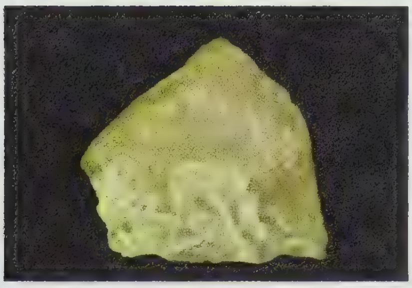

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Figure 4-30. Apatite.

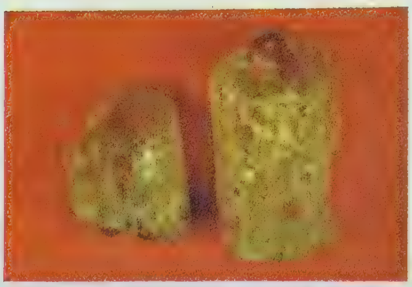

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Figure 4-31. Orthoclase Feldspar.

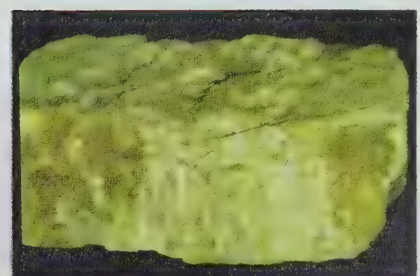

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Table 4-5. *Minerals With Nonmetallic Luster (Continued)*

Mineral	*Color*	*Streak*	*Hardness*	*Specific Gravity*	*Shape*	*Breakage Pattern*	*Other Properties*
*Quartz SiO_2	Colorless through various colors	Colorless	7	2.65	Hexagonal, massive	Conchoidal fracture	Waxy or glassy, species includes chalcedony, agate, onyx, rock crystal, and amethyst
*Topaz $Al_2SiO_4(F,OH)_2$	White, yellow, pale blue, pink	Colorless	8	3.5-3.6	Orthorhombic, massive	Perfect basal cleavage, conchoidal fracture	Glassy
*Corundum Al_2O_3	Brown, green, pink, blue, red, black, violet	Colorless	9	3.9-4.1	Hexagonal, massive	Conchoidal or uneven fracture, no cleavage	Barrel-shaped, dull in some varieties, may sparkle in gem varieties (ruby, sapphire), brittle, often tough
*Tourmaline series $(Na,Ca)(Al,Fe,Li,Mg)_3B_3Al_3(Al_3Si_6O_{27})(O,OH,F)_4$	Black, green, brown, white, red, blue	Colorless	7-7.5	3.0-3.3	Hexagonal, massive	Uneven to conchoidal fracture	Glassy, long direction often has fine parallel lines, brittle
Sulfur S	Yellow	Yellow to white	2.5	2.0	Orthorhombic, massive	Conchoidal fracture	Brittle, odor of sulfur, melts easily
Dolomite $CaMg(CO_3)_2$	White to pink to gray, green or black	White	3.5-4	2.8	Hexagonal	Rhombohedral cleavage, conchoidal fracture	Glassy to dull, will bubble with hot acid
Halite NaCl	Colorless, reddish, white, blue	Colorless	2.5	2.1	Cubic	Cubic cleavage, conchoidal fracture	Glassy to dull, salty taste, soluble in water
Hematite (red ocher) Fe_2O_3	Reddish brown to black	Reddish brown	6	5.3	Hexagonal massive	Uneven to conchoidal fracture, no cleavage	Dull to earthy, source of iron

*Valuable as gems or semi-precious stones.

Figure 4-32. Quartz.

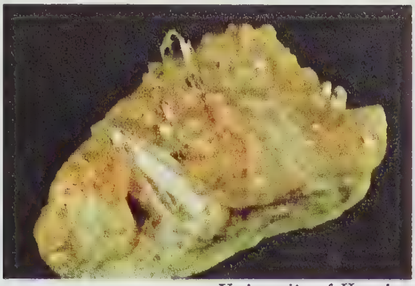

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Figure 4-33. Topaz.

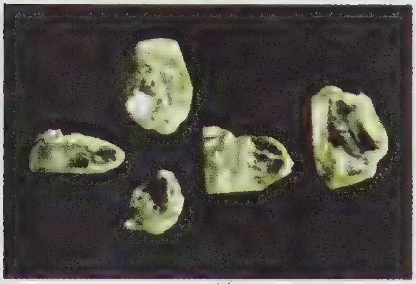

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Figure 4-34. Tourmaline.

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Figure 4-35. Sulfur.

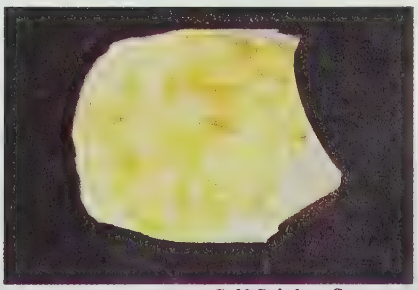

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Figure 4-36. Halite.

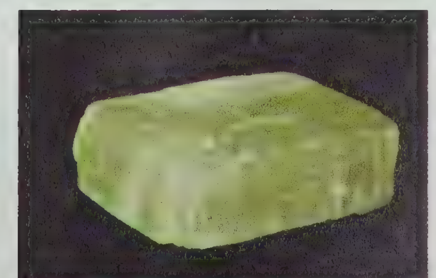

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Table 4-5. *Minerals With Nonmetallic Luster (Continued)*

Mineral	*Color*	*Streak*	*Hardness*	*Specific Gravity*	*Shape*	*Breakage Pattern*	*Other Properties*
Limonite (yellow ocher) $2Fe_2O_3 \cdot H_2O$	Yellow, brown, or black	Yellow brown	5.5	4.0	Massive, often powdery	No cleavage, conchoidal to earthy fracture	Dull to glassy, iron-rust appearance, coloring matter of soils
Serpentine $Mg_3Si_2O_5(OH)_4$	White, red, green, black, brown, yellow	Colorless	2-5	2.2-2.6	Monoclinic	Conchoidal fracture, none to fibrous cleavage	Silky, greasy to waxy
Asbestos (serpentine, chrysotile) $Mg_3Si_2O_5(OH)_4$	Green to yellow green	Colorless	2	2.2	Monoclinic	Fibrous cleavage	Silky, separates into thread-like fibers
Bauxite $Al(OH)_3$	Gray, red, white, brown	Gray	1-3	2.0-2.5	Rounded masses	Earthy fracture	Dull, source of aluminum
Hornblende $CaNa(Mg,Fe)_4$ $(Al,Fe,Ti)_3Si_6$ $O_{22}(O,OH)_2$	Green to black	Gray to white	5-6	3.4	Monoclinic	Cleavage in two directions, uneven to subconchoidal fracture	Glassy to silky
Kaolinite $Al_2Si_2O_5(OH)_4$	Red or reddish-brown to white or black	White	2	2.6	Triclinic	Earthy fracture, perfect basal cleavage	Dull, earthy odor, often pliable, greasy, used in ceramics
Augite (Ca,Mg,Al,Fe) $(Al,Si)_2O_6$	Black to dark green	Colorless	6	3.5	Monoclinic	Cleavage in two directions	Dull, granular
*Olivine $(Mg,Fe)_2SiO_4$	Olive green	Colorless	6.5	3.5	Orthorhombic, granular	Imperfect cleavage, conchoidal fracture	Glassy, common in meteorites
Muscovite $KAl_3Si_3O_{10}(OH)_2$	White to light gray	Colorless	2.5	2.8	Monoclinic	Perfect basal cleavage	Plates flexible and elastic, large crystals in pegmatites, member of mica group
Biotite $K(Mg,Fe)_3$ $AlSi_3O_{10}(OH)_2$	Black to dark brown	Colorless	2.5	2.8-3.4	Monoclinic	Perfect basal cleavage	Plates flexible and elastic, common mineral of pegmatites, member of mica group

*Valuable as gems or semi-precious stones.

Figure 4-37. Limonite.

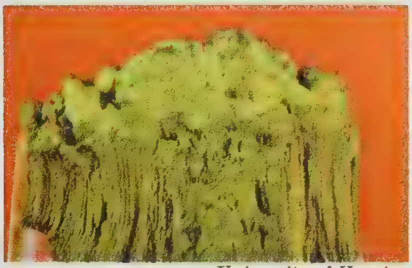

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Figure 4-38. Kaolinite.

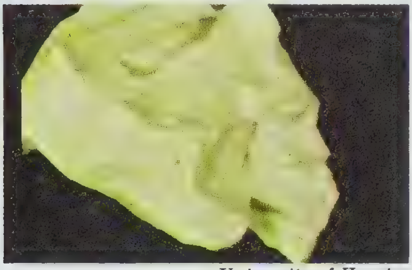

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Figure 4-39. Olivine.

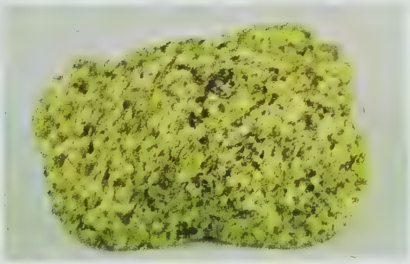

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Figure 4-40. Muscovite.

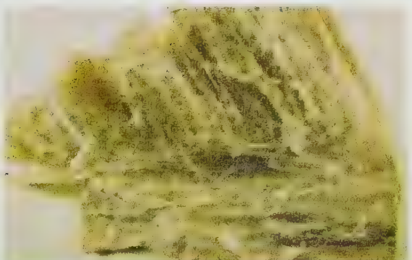

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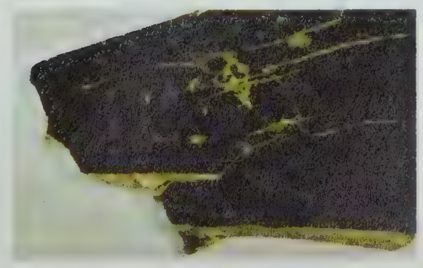
Figure 4-41. Biotite.



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4:3 Rocks

Rocks are single minerals or mixtures of minerals.

Rocks are single minerals or mixtures of several minerals that make up an essential part of the earth's crust. You may not have seen rocks exposed at the surface of the earth, because rocks are often covered by soil or vegetation. Nevertheless, at some depth below the surface, rocks are present everywhere. In mountainous areas, rocks extend skyward to great altitudes, and they have little covering of soil. In other regions, hundreds or even thousands of feet of sediments cover hard rocks below.

Rocks differ from one another according to their origin.

If you have seen rocks exposed at the surface, you may have observed that rocks are not all alike. Some look like hardened beach sand; some look like chalkboard chalk; some are hard, dense mixtures in which the component minerals are easily recognizable; other rocks look like cinders. Why are there differences among the rocks?

All rock materials originated beneath the present surface of the earth. The parent rock-forming liquid was carried to the surface and hardened there, or it hardened beneath the surface. All parent rock material, at one time in its history, was a liquid. When the liquid hardened, it formed *igneous* (ig′nee us) *rock*. Other kinds of rock have formed from the parent igneous rock.

Igneous rocks have hardened from a liquid.

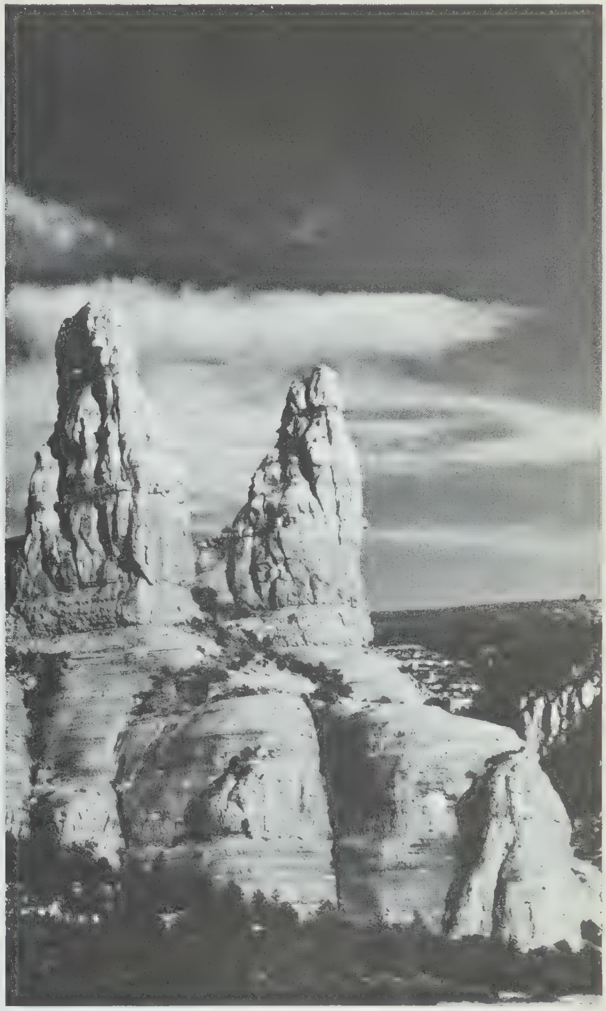
The name igneous comes from the Latin word *igneus*, which means fire. Vulcan (Vul′kan), the Roman god of fire, was supposed to be responsible for sending liquid rock upward from his realm within the earth to form volcanoes. From the name Vulcan comes the term *volcanic* to describe the material which erupts or flows from a volcano. Not all liquid rock reaches the surface. Much of it hardens at great depths. But igneous rocks have hardened from liquid material.

Chemical and mechanical changes called *weathering* occur when igneous rocks are exposed at the surface of the earth. Rock is broken into fragments, or it undergoes chemical reactions during which it is formed into new and different chemical compounds. Soil is produced by such changes. Materials formed during weathering are carried away by winds, waves, and rivers. Later the materials are deposited as sediments. Sand deposited on a beach and mud deposited by a flooding river are two examples of sediments. Eventually, older sediments are buried under layers of younger sediments. The weight of overlying sediments hardens the buried materials into *sedimentary* (sed i ment′a ree) *rock*.

Sedimentary rocks consist of older rock materials changed mechanically or chemically at the surface of the earth.

Robert F. Moseley, Jr.

Figure 4-42. Igneous rock that hardened near the surface but within a volcano remains as a high hill after softer surrounding rocks are worn away.



American Airlines

Figure 4-43. Sedimentary rocks have been uplifted and exposed to weathering and erosion after they were buried and hardened into rock.

When sedimentary rocks are buried to depths of 8 mi to 10 mi below the surface of the earth, they are subjected to great heat and pressure. Heat and pressure may cause physical and chemical changes that form new kinds of rock. Rocks changed by great heat and pressure beneath the surface of the earth are called *metamorphic* (met e mawr′fik) *rocks. Metamorphism* (met e mawr′fiz um) is a process that transforms sedimentary rocks and igneous rocks into new forms. Most metamorphic changes occur 8 mi to 10 mi below the surface. However, metamorphism occasionally occurs adjacent to hot igneous masses that are moving upward through sedimentary rocks that are close to the surface.

Metamorphosis is a Greek word that means to transform.

During the rock cycle, rocks are changed from one kind to another as environmental conditions change. There is no beginning and no end; nothing is lost, but everything undergoes change.

Figure 4–44 illustrates the never-ending cycle of rock change and re-formation. Sedimentary rocks are placed at the top of the triangle because they form at or near the top of the earth's surface. Igneous rocks and metamorphic rocks occupy the lower points of the triangle because these rocks are formed far below the earth's surface. Other kinds of rock may be transformed into metamorphic rocks by heat and pressure. However, metamorphic changes occur while the rock remains solid and temperatures are below the melting point. If temperatures rise to the melting point and the rock becomes a liquid and then hardens, the new rock is called igneous. Upward-pointing arrows indicate that both igneous and metamorphic rocks may be changed to sedimentary rocks if they are exposed at the earth's surface. Downward-pointing arrows indicate that sedimentary rocks may be metamorphosed and form metamorphic rock far below the surface. Or rocks may be melted at great depths to form igneous rock.

No cycle diagram can show all of the complex history of rock change and re-formation. For example, this diagram does not show that volcanic rock which forms at the surface may be metamorphosed if it is buried. However, the diagram shows how the majority of rocks are formed. Notice that none of the

Figure 4-44. The cycle of rock change and re-formation is never-ending. Each kind of rock occupies a peak of the triangle for a short time before it is subjected to change and becomes a different kind of rock, occupying a new position.

matter of the crust is permanently lost and none remains permanently in one form. All matter is subject to chemical change or rearrangement of its particles, but the elements still remain the same.

Rock identification follows the same general principles as mineral identification. In the following activity, you will examine mixtures of several minerals in the rocks. The first step in rock identification is to classify, or group, similar materials. All members of one group must have a common characteristic. Different groups have different characteristics. The purpose of classification is to simplify the understanding of materials.

ACTIVITY. Examine from five to eight rock samples of different shapes and sizes. Group all rocks that have a common characteristic. Make at least three groupings of the rocks. Record the common characteristic on which you base each grouping. Compare your system of classification with the classification made by other students. Use a 10X magnifying glass to find characteristics not observable without the aid of magnification. Without a microscope, you cannot see all of the distinguishing features which geologists use for precise classification. However, you can see the same characteristics that early scientists used for rock classification.

Crush bits of the rocks. Examine the crushed rock with the magnifying glass. If you recognize any of the minerals, write their names in your notebook. Would you now change your classification or group your rocks any differently?

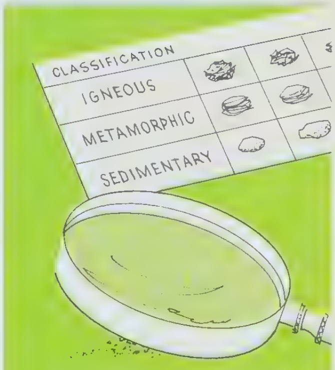


Figure 4-45.

MAIN IDEAS

1. The outer, solid crust of the earth, called the lithosphere, is composed of rocks and minerals. Rocks are made of single minerals or mixtures of minerals; minerals are elements or chemical compounds.
2. Only 12 of the 2,000 known minerals are common in the lithosphere.
3. Only 8 of the 88 crustal elements make up 98.58 percent of the lithosphere.
4. Minerals are naturally formed, inorganic solids that have a definite internal atomic pattern and a constant chemical composition.
5. Crystals of a given mineral always have the same kind of atoms arranged in the same pattern which is repeated over and over until the structure becomes visible.

6. One atom may substitute, up to a certain point, for another atom in a mineral if the ions involved have the same radius and the same electrical charges.
7. Given in order, the most common minerals of the lithosphere are silicates, carbonates, and oxides.
8. Minerals are recognized by the physical properties of form, hardness, luster, streak, fracture or cleavage, color, and specific gravity.
9. Mineraloids may occur as amorphous solids with no apparent internal atomic pattern. Mineraloids are not distinguished from minerals in most identification charts.
10. Cleavage is smooth, flat breakage in one or more directions. Fracture is uneven breakage with a curved (conchoidal), rough, or hackly surface.
11. Rocks are composed of single minerals or mixtures of minerals and are named igneous, sedimentary, or metamorphic according to their origin.
12. Igneous rocks, the source of all other rocks, are hardened from liquid rock material.
13. Sedimentary rock materials are formed by the mechanical breakdown and chemical changes which other kinds of rocks undergo when exposed at the surface. Sediments must be buried and hardened to form sedimentary rock.
14. Metamorphic rocks, which may have either igneous or sedimentary sources, result from deep burial and great heat and pressure.
15. The rock cycle is a never-ending process in which all rocks are changed, but matter is not lost.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

amorphous	igneous	sedimentary
cleavage	lithosphere	solid
crystal	luster	specific gravity
fracture	metamorphic	streak
hardness	mineraloid	weathering

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Only 33 elements have been found in the earth's crust.
2. Oxygen is the most abundant element in the earth's crust.
3. Mohs scale of hardness is a convenient scale to use on a field trip.
4. Diamonds will scratch all other minerals.
5. Color is an excellent means of identifying most minerals.
6. The most common minerals on the surface of the earth are silicates.
7. Minerals do not change their internal atomic patterns.
8. Iron and oxygen combine to form silicates.
9. Quartz is a mineral.
10. Most minerals are chemical compounds.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. The earth's crust contains (*77, 88, 99*) different elements.
2. Of the elements in the crust, only (*6, 8, 10*) are abundant.
3. Crystals of a given mineral (*always, occasionally, never*) appear in the same crystal system.
4. One mineral with a distinct taste is (*quartz, garnet, halite*).
5. (*Sedimentary, Igneous, Metamorphic*) rocks are the most abundant rocks.
6. In the rock cycle, none of the matter is (*permanently lost, changed, rearranged*).
7. (*Streak, Luster, Crystal habit*) is the color of the powdered mineral.
8. If a mineral breaks with a smooth plane surface, it is said to have (*luster, hardness, cleavage*).
9. An important means of distinguishing between the amphiboles and the pyroxenes is (*fracture, cleavage, streak*).
10. Odor is a unique characteristic of (*sulfur, halite, jade*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. A mineral must be formed in nature, of a definite internal atomic pattern, of a constant composition, __?__, and __?__.
2. The two most abundant elements in the crust of the earth are __?__ and __?__.
3. Quartz is composed of __?__ and __?__.
4. Rocks may contain more than one __?__.
5. Hardness is a(n) __?__ property of a mineral.
6. The way in which a mineral breaks is called __?__ or __?__.
7. The way light is reflected from a mineral is termed __?__.
8. Minerals may occur as crystals or they may be __?__.
9. Minerals have geometric shapes which belong to one of the six __?__.
10. Gold has a(n) __?__ luster.

D. How and Why

1. How does a mineral differ from an element?
2. Is coral properly classified as a mineral?
3. How does a mineral differ from a rock?
4. Why are some minerals found as crystals and others as massive occurrences?
5. Why are silicate minerals the most common minerals?
6. What elements would you expect to combine most often with the silicates?
7. Why do igneous and metamorphic rocks change at the surface of the earth?
8. Explain the meaning of the rock cycle diagram in Figure 4–44.
9. Why do metamorphic rocks form at depths but not at the surface of the earth?
10. Discuss the physical characteristics that aid in identifying common minerals.

INVESTIGATIONS

1. Explain why rocks and minerals and many earth processes have Greek and Latin names.
2. Look up the myths of Pluto and Vulcan. Why are some rocks called plutonic?
3. List five minerals that are important in industry or as gems. Discuss why they are not among the rock-formers.
4. Discuss the difference between fracture and cleavage. Use a block of four soda crackers to demonstrate the difference in the appearance of the breaks.

INTERESTING READING

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Pearl, Richard M., *Rocks & Minerals*. New York: Barnes & Noble, Inc., 1956.

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* Well-illustrated material.

Igneous Rocks

Igneous rocks have been forming since the earth was formed. They compose 95 percent by volume of the crust of the earth and are the parent materials for all other kinds of rock. Most igneous rocks are hidden, but in regions of volcanic activity, such as Hawaii, igneous rocks are still forming. Some scientists believe that all of the earth's crust is the result of volcanic activity. At the rate volcanic material is accumulating in the Islands of Hawaii and around other volcanoes, the present volume of the crust of the earth could well have accumulated during the approximately 4.5 billion years the earth has existed.

5:1 *Origin*

Igneous rock is formed by the solidification of liquid magma.

Rocks are called **igneous** (ig′nee us) if they have hardened or solidified from liquid rock. Liquid rock, called **magma** (mag′ma), forms within the upper mantle or near the bottom of the crust in certain regions. Magma then moves upward into the crust, or it flows out on the surface and solidifies as igneous rock. Melting of the mantle occurs only where temperatures are raised to approximately 1400°C (2552°F), or where the pressure is lowered. If the pressure is lowered sufficiently, the melting point of the mantle falls below 1400°C and melting may occur at lower temperatures.

Fractures are breaks in rock caused by intense folding or cracking.

At depths of 35 mi below the surface, the temperature of the mantle is estimated to be about 1400°C. This temperature is approximately equal to the melting point of rock under the pressure exerted by the weight of a column of rock 35 mi thick. Where concentrations of radioactive elements are present, temperatures may be raised above 1400°C. The additional heat energy is produced by changes in radioactive elements. Great

thicknesses of sediment, such as are present in areas of mountain building, prevent the escape of heat. Temperatures also tend to rise above 1400°C where sediments serve as a blanket to hold the heat within the earth. The melting point falls below 1400°C where the earth's crust is broken by fractures that extend into the mantle. Rocks melt at the lowered melting point associated with fractures. Magma uses the fractures as channels along which to move upward.

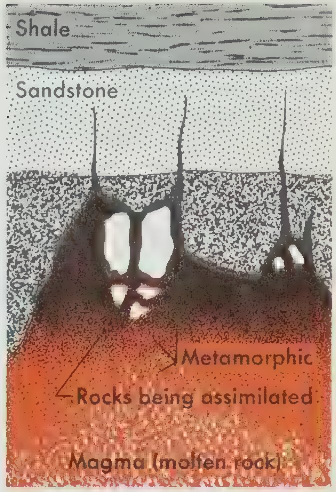


Figure 5-1. Magma ascends along fractures which allow liquid rock to surround and melt great blocks of solid rock.

Magma moves upward from depths of 35 mi to 50 mi below the surface of the earth. Sometimes it moves upward due to the great pressures associated with mountain formation. More often, however, magma rises toward the surface because it is less dense than the solid material around it. Occasionally, magma moves along great fractures. If the fractures are open to the surface of the earth, the liquid rock flows out on the surface in a form called *lava* (lahv′a). Sometimes the magma seems to rise through the solid rock in a process called *stoping* (stohp′ing). During stoping, great blocks of overlying rock are surrounded by the hot liquid rock. The blocks break up, melt, and become part of the magma. Magma works upward through regions that formerly were occupied by solid rock.

EXPERIMENT. Heat 2 cups of water until it boils. Then add ½ to ¾ cup of cream of wheat. The mixture should be very thick. As the cereal cooks, observe the surface. Why do craters form? How long do they remain? What gas escapes at the surface? Compare the processes that form the craters on the cream of wheat with processes that form volcanoes.

Figure 5-2.

5:2 Rock Bodies

When magma cools, it solidifies and forms rock bodies of many different shapes and sizes. These rock bodies are named according to their dimensions and relationship to the surrounding rock. Some magma hardens and forms rock far below the surface of the earth; some magma reaches the surface where it forms *volcanic mountains* and *volcanic plateaus* (pla tohs′).

Magma may be cooled and hardened below the surface, or it may pour out of volcanoes and harden on the surface.

Batholiths (bath′a liths) are the largest rock bodies. They form several miles below the surface of the earth. They may be 50 mi across and extend hundreds of miles. Batholiths are exposed at the earth's surface only when miles of surface rock have been carried away from above them. **Stocks** have the same general characteristics as batholiths but are smaller.

Often, precious metals and other ores are found associated with the country rock surrounding the batholith.

Liquids and gases that are less dense than the main mass of the magma rise to the top of the batholith. They often carry precious metals and valuable ores to the top of the batholith. Because the liquids and gases are able to move about more freely than the thicker rock magma, they squeeze into the rock that surrounds the batholith. Metamorphic changes often result from *intrusion* (in troo′zhun) of liquids and gases into adjacent rock which is called **country rock** by miners and geologists.

Other rock bodies formed by igneous activity are *dikes*, *sills*, and *laccoliths*. When the rock hardens in cracks that cut across the country rock, the body is called a **dike.** If the magma squeezes between two layers of rock and hardens, the body is known as a **sill.** A **laccolith** (lack′a lith) is formed in much the same way as a sill, but the magma layer develops a convex (kahn veks′) upper surface before it hardens and the body becomes mushroom-shaped. These rock bodies are illustrated in Figure 5–3.

Rock bodies formed on the surface may be volcanoes (cone-shaped, shield-shaped, or a combination of these types) or volcanic plateaus.

Volcanoes are rock bodies formed on the surface of the earth by magma that remains liquid until it reaches the surface. Some volcanoes are cone-shaped because the magma materials are blown out from an opening in the earth with explosive force. Fragments of rock settle back to earth around the opening and, after many eruptions, high mountains are formed from the cinders. Some volcanoes are shield-shaped. When the liquid rock reaches the surface, the lava flows out quietly around a central opening. Gradually, the hardened lava builds up a

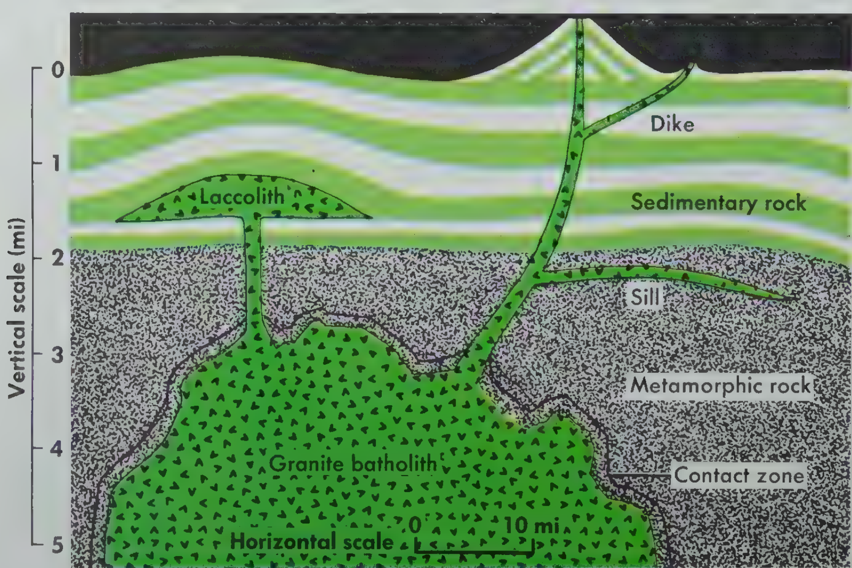


Figure 5-3. Large igneous bodies tend to be coarse-grained because they cool slowly. Because dikes and sills cool more quickly than laccoliths and batholiths, they are finer grained. Heat and gases escaping from the batholith cause the enclosing rock to become metamorphosed.

G. W. Stose, U.S. Geological Survey

Figure 5-4. Dikes may form ridges at the surface that extend for miles after erosion has removed the less resistant surrounding rock.

mound that resembles a warrior's shield. The Hawaiian Islands are typical shield volcanoes built up 30,000 ft above the ocean floor. Occasionally, lava flows out from long fractures extending for hundreds of miles. The hardened lava may be thousands of feet thick and hundreds of square miles in area. Such flows are called *volcanic plateaus.*

EXPERIMENT. Set the large end of a funnel or the stem of a coffee percolator in a pan of water. Build a cone of modeling clay around the stem. Be sure not to cover the opening at the top. Set the pan over a Bunsen burner or an alcohol lamp and heat the water until it erupts from the opening at the top. What causes the eruption? Now cover the opening with a very thin piece of clay. (Squeeze the clay between your fingers until it is no thicker than a piece of paper.) The clay should just cover the opening. Repeat the experiment. What happens to the clay covering the opening? Compare the processes you observe in this experiment with those of a volcanic eruption.

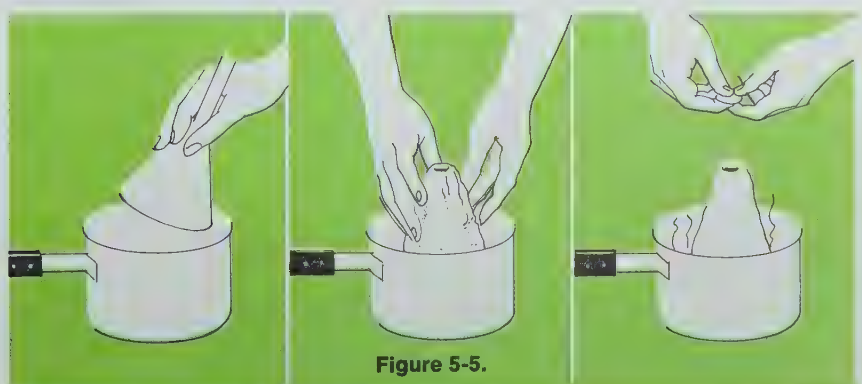


Figure 5-5.

5:3 Texture

The term **texture** (teks′cher) in igneous rock refers to the size of the mineral grains. Magma that solidifies at great depths cools slowly. Large masses of magma may require many millions of years to reach the temperature of the surrounding rock. During this slow cooling, minerals grow large and become recognizable. The rocks which contain large crystals are called **intrusives** (in troo′sivs) and are described as coarse-grained.

Intrusive igneous rocks harden slowly below the surface and have large mineral crystals.

Magma that reaches the surface may solidify in a matter of days or even hours. Rocks formed during rapid cooling have small crystals or no crystals. These rocks are called **extrusives** (ik stroo′sivs) and are described as fine-grained or glass. Minerals in an extrusive rock can seldom be recognized without the aid of a microscope. Indeed, many extrusive rocks form so quickly that atoms have no opportunity to adopt a geometric arrangement. Such rocks are called *glass*, and they have the same chemical and physical properties as man-made glass.

Extrusive igneous rocks harden quickly at the surface and have small mineral crystals or no crystals.

Occasionally, while the magma is still at great depth, some of the minerals crystallize; but before the entire magma solidifies, it rises to the surface. There the final cooling occurs rapidly. Rocks formed in this way are called *porphyries* (pawr′fa reez). They contain two or more noticeably different grain sizes.

Porphyries contain two or more noticeably different mineral grain sizes.

Igneous rocks have all gradations of mineral sizes because the size of the crystals depends upon the rate of cooling. The rate of cooling ranges from extremely slow at depths of several miles, to intermediate at depths of one mile or less, to very rapid at the surface. Batholiths cool very slowly and they have

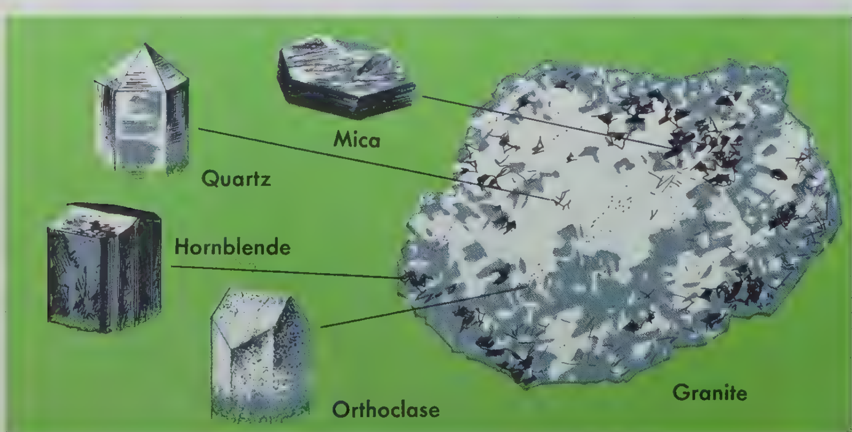


Figure 5-6. Granite forms from magma that cools slowly and each mineral component can be seen without magnification.

large crystals; laccoliths, sills, and dikes have recognizable crystals, but the grains are commonly smaller than those of a batholith. Volcanic materials cool very rapidly. Their minerals can be recognized only with the aid of a microscope, and if a glass forms, no crystals are visible.

Size of the mineral grains depends upon the rate of cooling of igneous rock.

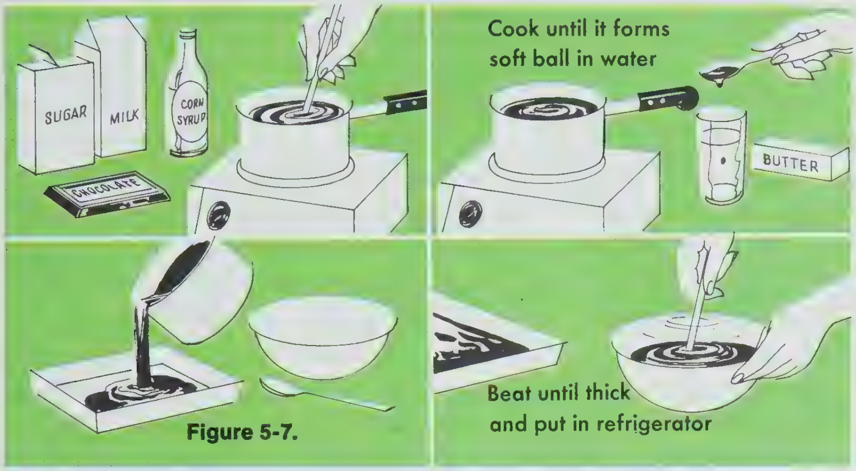


Figure 5-7.

EXPERIMENT. Caution: This experiment cannot be done successfully with packaged fudge. *Cook 2 cups of sugar, ¾ cup of milk, 2 squares of chocolate, and 2 tablespoons of light corn syrup slowly until the chocolate melts, stirring gently. Boil without stirring to 112°C (234°F) or until the mixture forms a soft ball when dropped into cold water. Remove the mixture from heat, add 2 tablespoons of butter, and let stand until cool. Pour half of the mixture into a pan and let stand. Pour the other half into a bowl and beat until thick. Place this half of the fudge in the refrigerator until hardened. Compare the textures of the two batches of fudge. Which one has the larger grains? Which batch is like an intrusive igneous rock? Which is similar to an extrusive igneous rock?*

EXPERIMENT. Stir 2 yeast cakes in 2 cups of lukewarm water. Stir in enough flour to make a thick dough (6 to 7 cups of flour). Mix thoroughly and allow to rise in a warm place (near a radiator or on a sunny window sill) until double in size. The time required will be between 1 and 2 hours, depending on the temperature of the room. When the dough has risen, cut through the mass and observe what happens. What causes the holes? Where did the gas come from? Why did it tend to rise to the top of the dough? What rocks may be compared to the dough, so far as texture is concerned?

Figure 5-8.

Figure 5-9. Oxygen and silicon atoms are the most abundant elements in a magma. They combine in a ratio of four oxygen atoms to one silicon atom to form the silicate tetrahedron. Atoms of other elements join the silicate tetrahedron to form a variety of rock-forming minerals.

5:4 Composition

Rock-forming minerals are combinations of the eight most abundant elements of the earth's crust: oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium. (Table 4–1.) A mineral whose presence is necessary to classify and name a rock is called an *essential mineral.* A mineral whose presence is not necessary for classification and naming of a rock is called an *accessory mineral.* Accessory minerals may or may not be present. Whenever they do occur, they are present in small amounts.

Oxygen and silicon, the most abundant elements in the earth's crust, join to form a unit called a *silicate tetrahedron* (sil′i kaet · te tra hee′dron). This silicate unit combines with one or more other elements to form the minerals found in igneous rocks. All igneous rocks contain one or more of the silicate minerals.

Members of the *feldspar family* are the most abundant of the igneous rock minerals. The feldspar family includes several members. *Orthoclase* (awr′tha klaes) is the most common feldspar. *Plagioclase* (plae′ji klaes) feldspars include a num-

American Airlines

Figure 5-10. Granite rock exposed to erosion in the White Mountains of New Hampshire has formed a resistant profile known as "The Old Man of the Mountains."

ber of different minerals, but their characteristics are so similar it is not important to differentiate among them. Plagioclase feldspars have fine, closely spaced parallel lines across the mineral faces. These lines reflect light in a way that makes the mineral seem to change color. The parallel lines distinguish plagioclase feldspars from orthoclase.

Most igneous rock minerals contain silicates (silicon and oxygen) combined with some other elements.

Silicate minerals containing iron and magnesium ions in combination with the silicate tetrahedron include the *amphibole* and *pyroxene* families, as well as *biotite* (bie′a tiet) and *olivine* (ahl′i veen). Igneous rocks commonly contain one or more minerals that contain iron and magnesium.

Quartz is a mineral that forms only when excessive amounts of silicon and oxygen are present in a magma. Quartz is not present in all igneous rocks, but it is abundant in some of them.

Quartz is formed from any excess silicon and oxygen which remains after other rock-forming minerals have solidified.

Micas (mie′kas) constitute another mineral family. *Muscovite* (mus′ka viet) is the light-colored mica and *biotite* is the dark-colored mica. These two minerals look alike except for their color. Micas do not make up a large proportion of any igneous rock, but they are usually present.

Table 5–1. *Mineral Families in Igneous Rocks*

Name	*Occurrence*
Feldspar	Most rocks
Orthoclase	Light-colored rocks
Plagioclase	Dark-colored rocks
Olivine	Rare
Pyroxene	Many rocks
Amphibole	Many rocks
Mica	Small amounts in most rocks
Quartz	Common

The minerals listed in Table 5–1 occur in various combinations or mixtures in igneous rocks. Sometimes differences in igneous rocks occur because the magma cools slowly, and the first minerals to crystallize sink to the bottom. The early-forming minerals occur together to form one kind of rock. The late-forming minerals solidify at the same time and form a different kind of rock. Variations in rock components also result during the stoping process. When country rock melts within a magma, the proportion of elements is changed. Rocks that solidify from such a magma have more silica than rocks that solidify from a magma that comes directly from the mantle.

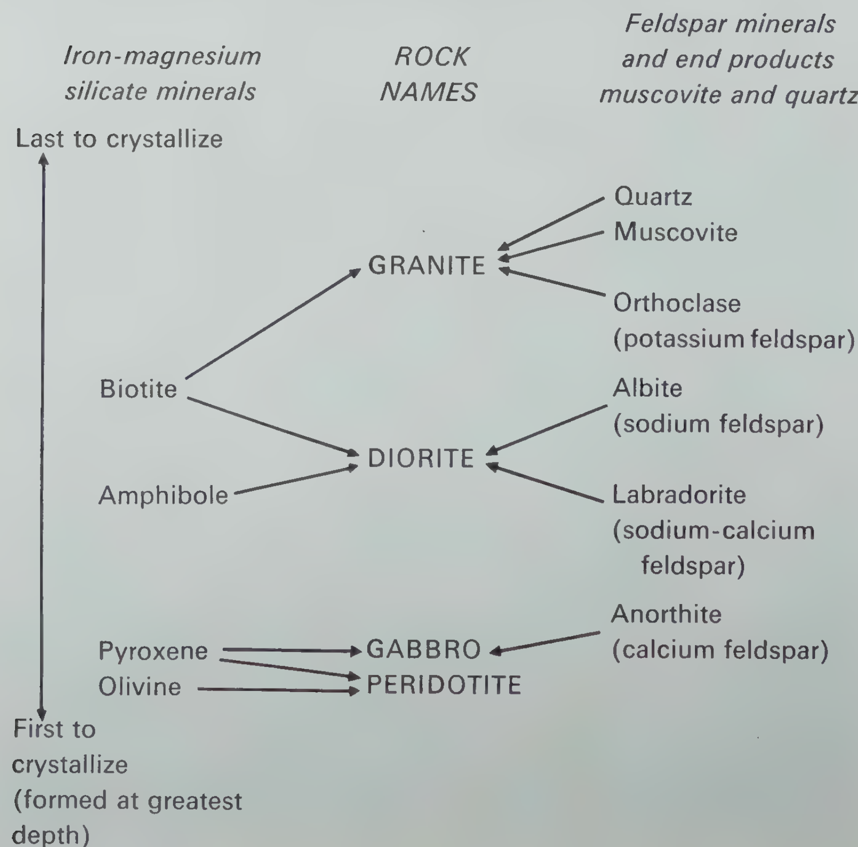
Minerals may crystallize from a magma at different temperatures.

Composition of a magma may be altered by the assimilation of country rock.

Table 5–2 shows the order in which minerals of a magma tend to crystallize. Overlapping of minerals occurs, but, in general, rocks contain minerals which are grouped according to this simplified order of crystallization. Granites may overlie diorite, gabbro, and peridotite in this sequence, but at depths too great to be seen. If stoping occurs and other materials are added to the magma during melting of rock as the magma moves upward, granite might occur without the other rocks being present, even at depth.

Olivine, or olivine and pyroxene form *peridotite*; pyroxene and anorthite form *gabbro* (gab′roh); amphibole and either labradorite or albite, or a combination of the two feldspars form *diorite* (die′a riet); orthoclase and quartz form *granite*. Small amounts of amphibole or biotite may be present in granite. Small amounts of muscovite may be present in granite and diorite. Rock names are based on kind and amount of feldspar or, if feldspar is absent, on kind of iron-magnesian mineral.

Table 5–2. *Order of Crystallization from a Magma*



5:5 Classification

Classification means the grouping together of objects that are similar, and the separation of objects that are different. Igneous rocks are classified and named according to their texture and mineral content. The igneous rock chart (Table 5–3) lists the names of common mineral mixtures and textures.

Igneous rocks are classified by texture and mineral content.

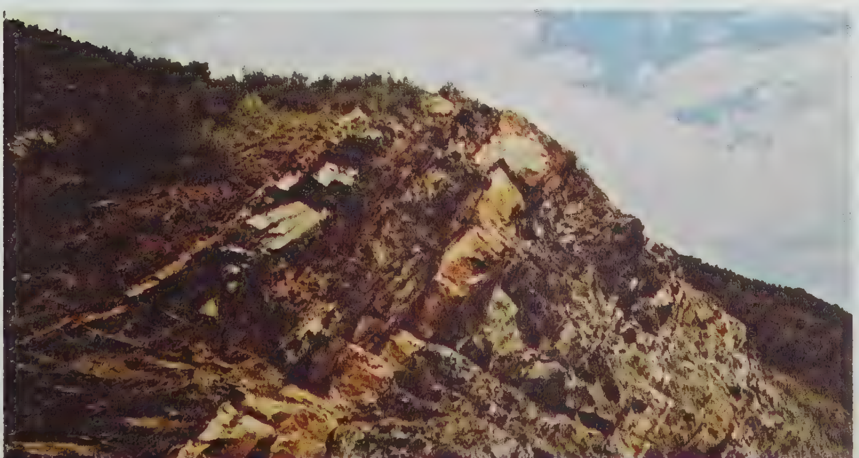
Coarse-grained, or **intrusive,** rocks include peridotite, gabbro, diorite, and granite. Each of these rocks may be porphyritic; that is, they may contain large crystals in a fine-grained mass. *Peridotite* is a mixture of olivine and pyroxene. *Gabbro* contains pyroxene and small amounts of plagioclase feldspar. *Diorite* has equal amounts of amphibole and plagioclase feldspar. *Granite* is a mixture of orthoclase feldspar, quartz, and small amounts of either amphibole or biotite. Orthoclase is the most abundant mineral in granite.

Granite is the most abundant of the coarse-grained rocks. Diorite is the next most common rock among the intrusives. Batholiths, which are massive rock bodies, almost invariably are made up of granitic rocks.

Granite is the most abundant of the four common intrusive rocks which are granite, diorite, gabbro, and peridotite.

Fine-grained, or **extrusive,** rocks include basalt, andesite, and rhyolite. *Basalt* contains pyroxene, small amounts of plagioclase feldspar, and occasionally olivine. It is similar to a gabbro in composition, but differs from it in texture. *Andesite* (an′dee ziet), like diorite, contains amphibole and plagioclase feldspar in about equal amounts. *Rhyolite* (rie′a liet) is a mixture of orthoclase feldspar, quartz, and a small amount of either amphibole or biotite. Granite and rhyolite contain the same kind of minerals, but the textures differ.

Basalt is the most abundant of the extrusive rocks which are basalt, andesite, and rhyolite.



Paul W. Nesbit

Figure 5-11. A band of light igneous granitic rock intrudes into dark metamorphic rock.

During cooling, fine-grained rocks may trap gas which leaves openings as it escapes. Scoria and pumice are examples of this.

Occasionally, fine-grained rocks such as basalt trap gases within the rock. When the gases escape, they leave behind a rock that is full of openings. *Scoria* (skohr′ee a) is the name given to basalts with this type of texture. The mineral composition characteristic of granite and rhyolite commonly forms glass when it is cooled rapidly on the surface. The glass is called *obsidian* (ab sid′ee an), or if it contains many gas openings, it is known as *pumice* (pum′is). Pumice is so light-weight that it floats in water.

Andesite and rhyolite are called felsite if their mineral grains are too small for identification. Felsites are lighter colored than basalts.

Intrusive rocks are more easily classified than extrusive rocks because the coarse grains can be identified. Minerals in many fine-grained rocks can be recognized with the aid of a microscope. But if the minerals cannot be identified, both rhyolite and andesite are called *felsites* (fel′siets). Felsites can be differentiated from basalt by color and density. Felsites are lighter colored and less dense than basalts. Extrusive rocks are predominantly basalts. The Hawaiian Islands and the Columbia River lava flows of Oregon and Washington are examples of the immense volume of basalt that finds its way to the surface of the earth.

Figure 5-12.

ACTIVITY. Examine several specimens of igneous rock. Sort the rocks into groups labeled intrusive and extrusive. What is the basis for this grouping or classification? Examine each of the intrusive rocks and note the size of the crystals. Are all of the grains approximately the same size? If the sizes of the minerals vary noticeably, what type of rock is it?

Indicate that the rocks are igneous by labeling them I with India ink in a small area of white paint. Write a number after the I and list the rocks in your notebook in the order in which they are numbered. Examine each rock and determine what minerals are present. Record the name, texture, and mineral content in your notebook.

Why do rocks of the same composition sometimes have different sizes of crystals? What is the difference between a basaltic rock and a gabbro? What is the difference between a gabbro and a granite? What is the difference between a granite and a pumice? What two characteristics determine the name of a rock? Color is the chief clue to differentiating between felsite and basalt. What minerals are present in the basalt that are absent in the felsite? Check Tables 4–4 and 4–5 for the composition of these minerals. What elements are responsible for the dark color of the basalt? What other rocks owe their dark color to the presence of these elements?

Table 5-3. ***Igneous Rock***

Origin	*Texture*	*Name*	*Dominant Minerals*						
			Feldspars		Olivine	Pyroxine	Amphibole	Quartz	Mica
			Orthoclase	Plagioclase					
EXTRUSIVE	Glassy*	Obsidian	X				X	X	
		Pumice (with holes)	X				X	X	
		Scoria (with holes)		X	X	X			
	Fine-grained	Felsite							
		Rhyolite (P)	X				X	X	X
		Andesite (P)		X			X		X
		Basalt (P)		X	X	X			X
INTRUSIVE	Coarse-grained	Granite (P)	X				X	X	X
		Diorite (P)		X		X	X		X
		Gabbro (P)		X		X			
		Peridotite			X	X			

(P) may also have a porphyritic form.
*Minerals do not form, but elements for these minerals are present.

Figure 5-13. Pumice.

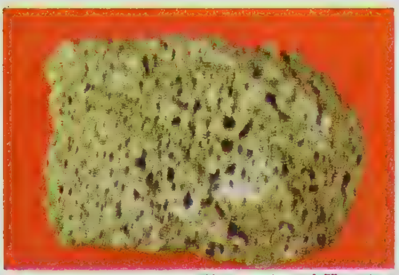


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Figure 5-14. Scoria.

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Figure 5-15. Rhyolite.

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Figure 5-16. Granite.

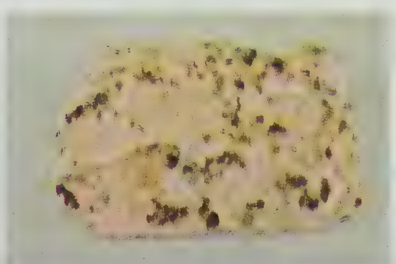

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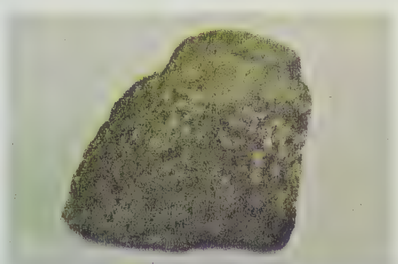
Figure 5-17. Diorite.



University of Houston

MAIN IDEAS

1. Igneous rock, which composes 95 percent by volume of the crust of the earth, is formed from liquid rock called magma.
2. Rock melts far below the surface when pressures are released by fracturing and the melting point is lowered or when the temperatures are raised above 1400°C.
3. Magma rises because it is under pressure or less dense than the surrounding rock. Magma may cool and solidify within the crust or on the surface.
4. Rock bodies formed beneath the surface include batholiths, laccoliths, sills, dikes, and stocks.
5. Lava is magma which reaches the surface of the earth. Lava may form volcanic peaks or volcanic plateaus.
6. Texture of igneous rocks is determined by the rate of cooling, which depends on depth and volume of the magma. Large rock bodies cooled below the surface (intrusives) tend to have large mineral crystals. Small rock bodies or rocks cooled on or near the surface (extrusives) tend to have small crystals or no crystals.
7. All igneous rock minerals contain silicon and oxygen. The silicate tetrahedron combines with other elements to form most igneous rock minerals. Quartz contains only silicon and oxygen.
8. The rock-forming minerals found in igneous rocks are: feldspars (orthoclase, plagioclase) most abundant, micas (muscovite, biotite), olivine, pyroxine, amphibole, and quartz.
9. Igneous rocks are classified by texture (glassy, fine-grained, or coarse-grained) and the mineral content.
10. The most abundant intrusive igneous rock is granite. The most abundant extrusive igneous rock is basalt.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

accessory	intrusive	plateau
batholith	laccolith	porphyry
dike	lava	stoping
extrusive	magma	texture

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Liquid rock is either lava or magma.
2. It is possible to see the crystals in pumice.
3. Pores in pumice are formed by escaping gases.
4. The crust of the earth has been built up by volcanic activity.
5. Stocks and batholiths differ only in size.
6. Rocks cooled on the surface have fine grains or none at all.
7. Porphyries are either intrusive or extrusive rocks.
8. All igneous rocks contain both silicon and oxygen.
9. Granite and basalt are both extrusive rocks.
10. Felsite is another name for basalt.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Igneous rocks which harden underground are called (*intrusive, extrusive, fine-grained*).
2. Pumice is a(n) (*intrusive, extrusive, coarse-grained*) igneous rock.
3. A slowly cooling magma produces a rock with (*large, small, no*) crystals.
4. Rock bodies which cut across country rock are called (*sills, dikes, laccoliths*).
5. Igneous rocks are named according to their mineral content and (*texture, color, hardness*).
6. All igneous rocks, except peridotite, contain some (*quartz, feldspar, pyroxene*).
7. All of the silicate minerals contain silicon and (*oxygen, iron, carbon*).
8. The most common of the intrusive igneous rocks is (*basalt, granite, felsite*).
9. The most common of the extrusive igneous rocks is (*basalt, granite, peridotite*).
10. Felsites include andesite and (*granite, rhyolite, obsidian*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The composition of a magma may be changed during the process called __?__.
2. Large crystals in igneous rock indicate that the rock is __?__.
3. Molten rock which pours from a volcano is called __?__.
4. __?__ has many gas openings that give it a frothy appearance.
5. Magma forms during melting of the upper __?__ or the base of the __?__.
6. Magma may reach the surface of the earth by following great __?__.
7. __?__ refers to the size of the mineral grains in an igneous rock.
8. An intrusive rock body which has a convex surface is a(n) __?__.
9. The most common mineral in igneous rocks is __?__.
10. The rock-forming mineral which contains only silicon and oxygen is __?__.

D. How and Why

1. Basalt, gabbro, and peridotite are among the darkest of the igneous rocks. What do these rocks have in common that might account for their color?
2. What changes in the country rock would you expect to find in the vicinity of a batholith?
3. Why are precious metals and other ores found near the top of a batholith rather than deep within it?
4. Why do the early-forming rock minerals sink to the bottom of the magma?
5. How could you distinguish between scoria and pumice without the aid of a microscope?
6. Why is it difficult to distinguish between andesite and rhyolite, even though diorite and granite may be rather easily identified?
7. Discuss reasons why rocks in a dike tend to be finer grained than rocks in a batholith.

8. Consult Table 5–2 before answering the following questions: Would olivine and quartz be present in the same rock? Would the calcium feldspar ever be present with quartz? Which iron-silicate mineral would form in association with the calcium-feldspar?
9. Man has reached depths of only 5 mi below the surface through drilling wells and mining operations. Discuss reasons why peridotite is the least common of all known rocks.

INVESTIGATIONS

1. Attach a thin slab of granite to a piece of cardboard with epoxy glue. Around the edge of the granite slab, draw and color an enlarged picture of any minerals you find in the granite. Attach a thread from the picture to the correct crystal in the slab. Make a diagram of basalt also if the basalt is porphyry or an amygdaloid (a mig′da lawid), a basalt in which the openings are filled with a different mineral. You will need a magnifying glass to see the basalt crystals. Display your investigation to the class.
2. Make a clay model of each of the various rock bodies described in this chapter. Explain the formation of each one for the class. Save the best models for a display.
3. If you have ever seen a volcano in action, describe what you saw to the class and explain the why and how of it.

INTERESTING READING

"Birth and Death of a Volcano; Myojin." *Life Magazine*, XXXIII (Oct. 13, 1952), pp. 129-30.

Fenton, C. L., and Fenton, M. A., *The Rock Book*. New York: Doubleday & Company, Inc., 1940.

Galt, T., *Volcano*. New York: Charles Scribner's Sons, 1946.

Hauser, E. O., "Will Vesuvius Blow Its Top Again?" *Saturday Evening Post*, CCXXVIII (Feb. 11, 1956), pp. 36-7.

*Matthes, Francois E., *The Incomparable Valley: A Geologic Interpretation of the Yosemite*. Berkeley, California: University of California Press, 1956.

* Well-illustrated material.

6 Sedimentary Rocks

Unlike igneous rocks, sedimentary rocks are exposed in many regions. In fact, they cover 75 percent of the surface of the earth. In spite of their wide distribution, sedimentary rocks make up only 5 percent of the volume of the earth's crust. The sedimentary cover has an average thickness of about 2 mi; igneous rocks have an average thickness of approximately 15 mi. You may have seen sedimentary rocks exposed along river banks or in highway excavations.

6:1 *Origin*

In the eighteenth century, James Hutton, a Scottish geologist, observed that the rocks of his native Highland area were undergoing constant change. He pointed out that the changes which rocks are undergoing now must be the same kind of changes that have occurred during all of geologic time. Hutton's observation led to the principle of **uniformitarianism** (eu ni fawr mi ter′ee a niz em), which says that *the present is the key to the past.* Geologists study the processes of the present for clues to the processes which were at work during past geologic time.

Have you ever seen a boulder with a crumbling surface, or the wind blowing dust and sand from place to place? Have you watched water flowing away after a rain and carrying mud and sand along with it? If so, you have observed some of the processes that change the surface of the earth.

Any rock that is exposed to sun, rain, air, plants, and animals undergoes change. Some changes are mechanical; some are chemical. Either alone or working together, the processes of change break down solid rock into small particles called **sediments.** Sediments are then buried and *consolidated* (kan sahl′i daet ed) or hardened into sedimentary rock.

All rocks exposed at the surface of the earth undergo either chemical or physical change.

Sedimentary rocks are formed from materials that are broken up at the surface, then carried away and deposited in a new environment. Sediments consist of fragments of igneous, metamorphic, or older sedimentary rocks. Some sediments are sand grains or clay. Other sediments are the soluble products formed by chemical reactions at the earth's surface. Eventually, all of the products of change accumulate in a new environment, where they may be buried under still younger sediments. During burial, the loose sediments are consolidated or hardened into solid rock.

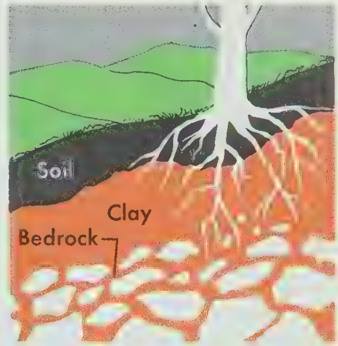


Figure 6-1. Soil, clay, and sand result from the weathering of hard rock. Weathering may be a chemical or mechanical process.

6:2 *Weathering*

Weathering consists of two processes in which rock is broken up in place, at or near the surface of the earth. *Disintegration* (dis int e grae′shun), a mechanical process, breaks large masses of rock into small fragments without altering the mineral components of the rock. *Decomposition* (de kahm pazish′un), a chemical process, alters the arrangement of atoms and forms new substances. Mechanical and chemical processes work together and, in time, break down even the most resistant rocks.

Disintegration is weathering by mechanical means. Decomposition is weathering by chemical means.

Several factors determine the rate at which rocks weather. The *kind of rock* is an important factor. Rocks that contain olivine, pyroxene, or amphibole decompose much more rapidly than others. Sandstones, shales, and limestones are subject to little chemical change. Metamorphic rocks, in general, decompose more rapidly than most igneous rocks.

Climate is also an important factor in the rate of weathering. Weathering is most rapid in tropical climates because abundant moisture and high temperatures hasten chemical reactions. Temperate climates also promote decomposition because water is present and temperatures are warm during the summer. Lack of moisture in deserts slows the weathering processes; in frigid regions, low temperatures delay surface change.

Cracks in rocks hasten weathering. Not only do such openings expose more surface area to chemical change, but they also promote mechanical weathering. Water and plant roots enter the cracks and exert pressure on the openings, forcing them farther apart.

Figure 6-2. What processes have caused weathering of these rocks?

Edward J. Webster

6:3 Disintegration

Rocks are broken into fragments by plants, animals, water and ice. Plants send their roots into any available opening. As the roots grow, they force the openings to widen. Burrowing animals make channels through rock, allowing water to penetrate to greater depths. When water freezes, it exerts pressure and forces openings farther apart because it expands. Ice wedging exerts great force in cracks. In temperate climates, alternate freezing and thawing occur almost daily during the winter. The result is disintegration. Forest fires, if followed by cooling rains, may cause rocks to split into fragments. Disintegration changes the rocks from large solid masses into small pieces. But disintegration does not change the substances of which the rocks are made.

Phyllis G. Lewis

Figure 6-3. Water cascades over Bridal Veil Falls, cutting downward in the solid rock of Utah's fault block mountains.

EXPERIMENT. Fill a cardboard container completely with water. Cover it tightly and place it in the freezing compartment of a refrigerator. After one day, remove the container from the freezer. What is the shape of the container? What does this show about the volume of ice as compared with the volume of water? Which is more dense, ice or water? Why would a glass jar not be a suitable container in which to freeze water? Compare the results of your experiment with the effect of alternate freezing and thawing of water in the openings of a rock.

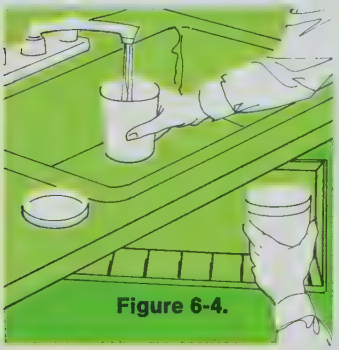


Figure 6-4.

6:4 Decomposition

Rocks are subject to decomposition in the presence of water. Water is most abundant in tropical regions. Even in arid regions, dew forms at night and chemical reactions between rocks and water are possible. Rainwater contains carbon dioxide in solution. This solution is a weak acid that reacts with rocks to form new chemical compounds. Decaying organic matter forms *humic* (heu'mik) *acid* in the soil. Humic acid also reacts with rock to form new substances. Some new compounds are carried away and only insoluble substances are left behind.

A solution is a mixture formed by dissolving a substance (a mineral, in this case) in a solvent (water, in this case).

Both igneous and metamorphic rocks decompose to form clay and soluble forms of silica and carbonates. During the decomposition of rocks, iron is released from its combination with silicon and oxygen. Iron reacts with oxygen from the air to form a new mineral, limonite ($Fe_2O_3 \cdot H_2O$). Limonite is the

Soluble means that a substance can be dissolved by a solvent and carried in a solution.

brown substance commonly found in sediments. Clay is the most abundant substance formed during decomposition. It is derived from both the iron-magnesian minerals and the feldspars. Quartz is changed very little by weathering processes. It is released from the solid rock in which it formed and becomes one of the common sediments.

Final products of decomposition are iron oxide, clay, and soluble forms of silica and carbonates.

6:5 *Products of Weathering*

Exfoliation domes are mountainous knobs of igneous rock that can be observed in regions of little vegetation. (Figure 6–6.) Thin plates or layers of loose rock cover the bare rock surface of the dome. Both mechanical and chemical processes produce exfoliation domes. Alternate wetting and drying loosen thin layers of surface material. After the overlying materials are removed, similar layers are produced as the igneous rock expands.

Spheroidal boulders are formed by weathering along rock fractures. Water trickles into the cracks and hastens decomposition of the rock surface. Water also freezes in the openings or simply fills the opening and exerts pressure. Great rounded boulders are common in regions of exposed igneous rock that has been subjected to weathering. (Figure 6–5.)

Soil is the most familiar product of weathering. It covers most of the land surface. Soil forms on loose rock waste, or

W. T. Schaller, U.S. Geological Survey

Figure 6-5. Rapid weathering of exposed corners and edges of gabbro rock has formed this spheroidal boulder.

F. C. Calkins, U.S. Geological Survey

Figure 6-6. Weathering of exposed mountain tops such as Half Dome in Yosemite National Park, California, causes layers of rock to split from the surface to form exfoliation domes.

mantle rock, formed by weathering. Mantle rock is usually only a few feet thick and should not be confused with the interior layer of the earth called the mantle.

In humid climates, plants grow in the mantle rock as soon as it is sufficiently weathered for roots to penetrate it. Decayed plant matter accelerates the chemical change of feldspar and iron-magnesian minerals to clay and limonite. Soil is a mixture of *humus* (decayed organic matter), clay, limonite, and sand grains which have been separated from the original solid rock. Clay tends to move downward, carried by rain water that enters the soil. The upper few inches of soil retain the humus, sand grains, a little clay, and limonite. Soluble matter is carried away, except in arid regions.

Residual (ri zidj'wal) *soils* are soils that have formed above the mantle rock. Mantle rock grades downward into broken rock, and then into solid, unweathered rock. Soil that forms on loose mantle rock that has been transported to the area by winds or rivers is called *transported soil.* Transported soils and the mantle rock from which they form have no relationship to the solid rock beneath them. In humid regions where vegetation is abundant and slopes are gentle, the residual soils are thick. Soil is thin or absent on steep slopes because it is rapidly carried downward by rain or gravity as soon as it forms. Soil is also thin in arid regions and even in humid regions where the lands are plowed. Winds carry soil away if no vegetation is present to anchor it. During a period of drought in the early 1930's, great dust storms swept the Great Plains of the United States and stripped the land of much of its fertile soil.

Precipitate means to separate a substance from a solution by a chemical reaction. **Precipitate** also means the substance which is separated by the chemical reaction.

Sedimentary rocks are products of weathering that have been consolidated into hard layers. Like soils, sedimentary

Figure 6-7. Many farms have been abandoned when unprotected, dry topsoil is removed during widespread dust storms.

rocks consist of clay, sand grains, and limonite. Unlike soils, sedimentary rocks may consist of layers of soluble substances which have been precipitated as solids. Sedimentary rocks also include layers of large fragments like the mantle rock.

Figure 6-8. Boulders too heavy for the stream to carry are left in the stream bed. Finer materials are carried downstream.

6:6 *Clastics*

Clastics are sedimentary rocks made of fragments and grains of quartz, feldspar, shells, clay, and even pebbles and boulders. These materials are carried in suspension by rivers, winds, waves, or glaciers. With the exception of glaciers, the ability of these agents to carry materials depends on their velocity. Materials are deposited as the speed of the carrying agent decreases. Usually the velocity decreases gradually and the clastics are sorted according to size and specific gravity. Large fragments are dropped first, intermediate sizes are dropped next, and fine sediments are deposited last. Materials transported by a glacier are not sorted because all sizes are dropped when the ice melts.

EXPERIMENT. Stir sand, clay, and rock fragments in a glass jar of water. Allow the materials to settle. What is the appearance of the water after all of the materials have settled? What is the distribution of sediments? Compare this distribution with the layering of sediments in a quiet body of water.

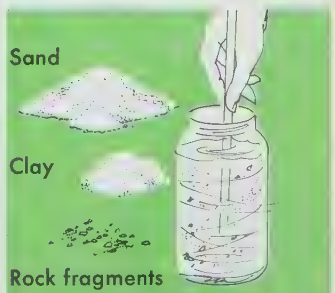


Figure 6-9.

Clastic rocks are named according to the size and shape of the fragments they contain. They include conglomerate (kon-glahm′e rit), breccia (brech′ee a), sandstone, siltstone, shale, and tillite (til′ite), a glacial deposit. (Table 6–1.) *Conglomerates* are mixtures of rounded pebbles and some clay or sand. The pebbles may be any kind of material. *Breccia* is similar to conglomerate in composition, but the shape of the fragments is angular instead of rounded. Conglomerates are more common than breccias because angular edges tend to be worn during transportation and this results in rounded pebbles.

Clastics include conglomerates, breccia, sandstone, siltstone, shale, and clay.

Sandstone consists of smaller grains than those of conglomerate. Beach sands and river sands are typical of the material in sandstone. Fragments of sand are easily seen and they feel gritty to the fingers. Sandstones are usually made of quartz, but they may contain feldspar, fragments of basalt, or even calcite. The composition depends only upon the kind of rock from which they have been weathered.

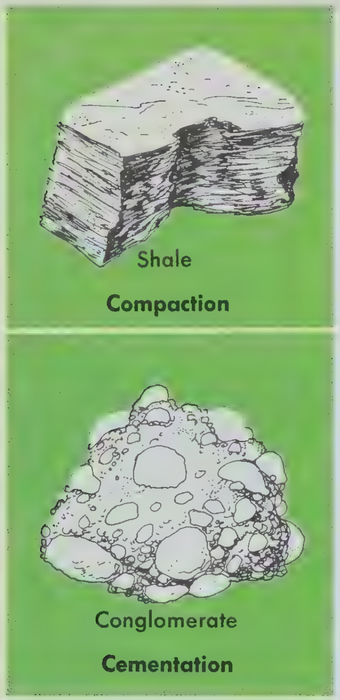


Figure 6-10. Compaction and cementation are effective lithifying processes.

Siltstone is like sandstone except that the grains are much finer. It may be necessary to examine siltstone with a magnifying glass to see the texture. Usually the surface feels gritty. Some clay is often present.

Shale is made of thin layers consisting of clay fragments too small to be seen without magnification. Mica flakes also are common. Shale is distinguished from siltstone by its smooth, almost slippery feel.

Clastics are hardened into rock by *compaction* (kom-pak′shun) and *cementation.* Mud balls and mud pies demonstrate how readily clay is hardened simply by **compaction,** or squeezing, and drying. During burial, water and air are squeezed out of the original mud, and tiny clay fragments become arranged in layers to form shale. Clay particles are pressed together so tightly that water does not move through shale. Siltstone, sandstone, and conglomerate undergo some compaction, but compaction alone does not produce hard rock from these materials.

Cementation, the deposition of cement between fragments, is necessary for the consolidation of siltstone, sandstone, and conglomerate. Waters that move through loose sediments carry cementing materials in solution. Chemical reactions cause these cementing substances to come out of solution. Cement is deposited around the various grains and pebbles, and holds them together in a solid mass. Calcite is the most common cementing material; silica is the next most common. Clay or iron minerals hold some sediments together. Cement fills many former spaces between sediments, but sandstones and conglomerates tend to retain some openings through which water moves. Such rocks are both *porous* and *permeable* (pur′mee a bul). Porous rocks contain openings; permeable rocks contain openings that are connected and capable of transmitting a fluid.

Calcite and silica are the most common cementing agents. Clastics are often colored by iron stain, organic matter, or volcanic debris.

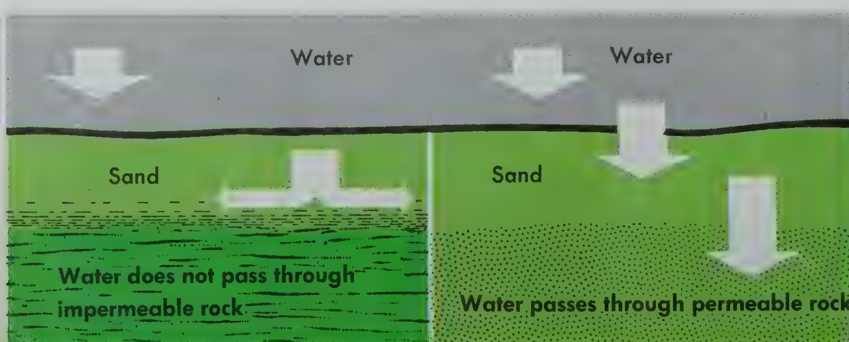


Figure 6-11. Oil and groundwater flow through permeable rocks such as sandstone but cannot flow through impermeable rocks such as shale.

Clastics are colored red, yellow, or brown by iron stain or iron cement. They are colored black by finely divided organic matter, or green by decomposed volcanic debris. The most common colors are due to iron.

EXPERIMENT. Make six different mixtures of sand, gravel or pebbles, clay, patching plaster, and water. Be sure that you have one mixture of sand and water, one mixture of clay and water, one mixture of patching plaster and water. Other mixtures can be various combinations of gravel or pebbles with different amounts of clay and plaster or sand and plaster. Use just enough water to make a stiff mixture. Place each mixture in a paper cup or cut-off milk carton. Put all of the containers in an oven. If you use a gas oven, the pilot light will furnish sufficient heat. If you use an electric oven, set the temperature control at 200°F. When the oven has reached this temperature, turn off the heat. Let your mixtures stand until all of the water evaporates. Examine each mixture. Are any mixtures still loose? Are any of the mixtures cemented together? If so, what is the cementing agent? Label each of the synthetic rocks with the name of the sedimentary rock it resembles.

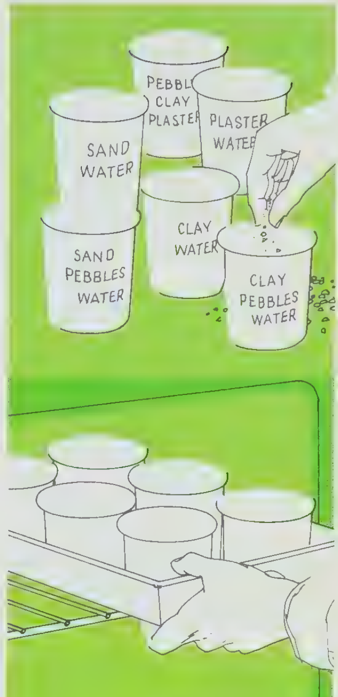


Figure 6-12.

6:7 *Nonclastics*

Nonclastics are sedimentary rocks formed by chemical and organic processes. Chemical processes include both evaporation and precipitation (pri sip i tae′shun). Substances formerly carried in solution are deposited when the water in which they are dissolved evaporates. Products of evaporation are called *evaporites* (i vap′a riets). They include solid crystalline minerals of calcite, halite, and gypsum (jip′sum), or alabaster (al′a bas ter). *Precipitates* form when water moving through the ground comes in contact with certain substances that cause a chemical change in the solution. As a result of the change, solids are formed that precipitate out of solution. Much of the world's limestone is a precipitate consisting of the mineral calcite. Precipitates are also notable in association with some of the ores and minerals that are important in industry. (Section 8:2.)

Nonclastics, formed by chemical or organic means, include precipitates, evaporites, and coal.

Precipitates include limestones, some ore minerals, and chert.

Organic deposits may result from animal or plant processes. Animals form shells or bones from calcite or silica in seawater. They also build reef structures of calcite. Such materials accumulate to form hundreds or even thousands of feet of rock.

Organic deposits include reefs, peat, lignite, and bituminous and anthracite coal.

Figure 6-13. Cochina limestone.

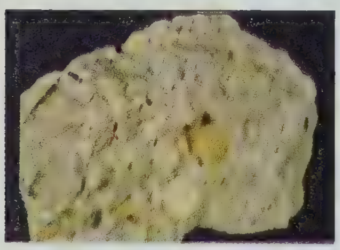


Figure 6-14. Fossiliferous limestone.

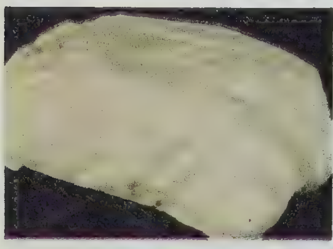


Figure 6-15. Chalk.

Photos From University of Houston

Plant debris, such as trees, twigs, and ferns, is buried in swamps. Vegetation decays partially beneath the swamp water, and eventually forms layers of peat, lignite, and coal.

Nonclastics are named according to their composition. They include *limestone*, composed of calcite; *flint* or *chert*, made of silica; *rock salt*, made of the mineral halite; and *alabaster*, made of either the mineral gypsum or anhydrite (an hie′driet). (Table 6–1.) Nonclastics are solid substances in which the crystals interlock during precipitation or evaporation. No open spaces are present in these nonclastics unless they form after deposition.

Coal, another nonclastic rock, is made of the remains of plants. The varieties of coal include *peat* and *lignite* (lig′niet), the lowest grades, and *bituminous* (bi too′me nes) and *anthracite* (an′thra siet), the preferred fuel types.

Nonclastic rocks may be crystalline, with the crystal form readily visible to the naked eye. Cave deposits commonly have beautiful crystals that are large and well developed. On the other hand, nonclastic rocks may be made of microscopic crystals or shells too fine to be seen without magnification. *Chalk* is a variety of limestone consisting of calcite and shells so minute that they cannot be seen without the aid of a microscope. The rock has a white, powdery appearance.

ACTIVITY. Select sedimentary rocks from your own collection and unmarked rocks from the classroom collection. Group the rocks as clastic or nonclastic. Indicate that the rocks are sedimentary by labeling them S with India ink in a small area of white paint. Give each rock a number. List the rocks in your notebook (S-1, S-2, and so on). Name each rock. Check your samples for limestone and halite. Look for fossils, and note whether plants have been preserved in any of the specimens. Note any special features such as ripple marks, mud cracks, or concretions.

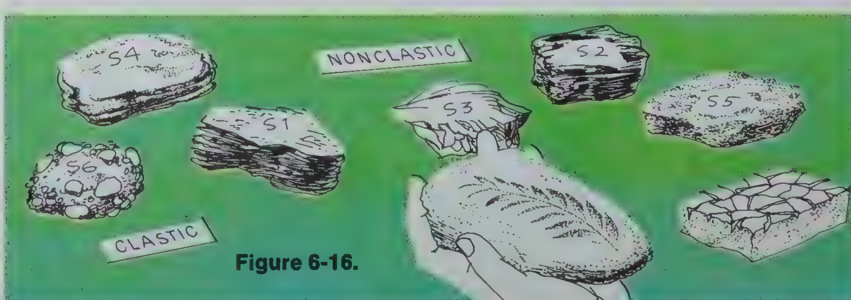


Figure 6-16.

6:8 Features

Sedimentary rocks are laid down in a series of distinct layers or beds similar to the layers in a cake. The individual layers, or **strata** (strae'ta), can be recognized because of differences in color, grain size, or composition. In a series of layered rock, the oldest bed lies at the bottom and the youngest bed lies at the top, unless crustal movements have taken place. The top layer becomes covered by a new type of deposit—usually a finer-grained rock—as an area sinks beneath the sea. Some series consist of conglomerate covered by sandstone and sandstone covered by shale. When shore zones emerge from the water instead of sinking, the series is often shale covered by sandstone and sandstone covered by conglomerate. Conglomerates are less common than sandstone or shale, and they may be absent from the series. (Figure 6–17.)

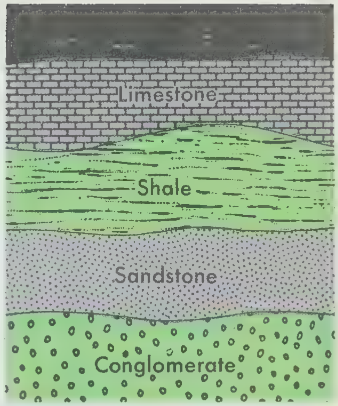


Figure 6-17. In cross section, sedimentary rocks show the layered effect resulting from changes in conditions of deposition.

Limestones are present in a sedimentary sequence only if the seas are warm and the water is clear with abundant calcite in solution, or if conditions are favorable for evaporation of seawater. Some limestone is formed from reworking a former limestone bed which has been eroded by waves and currents.

Limestones are present only under certain conditions.

Fossils (fahs'ils) are important components of many sedimentary layers. A fossil is any record of past life such as a bone, shell, or some other hard part of an animal or plant. Fossils may also be prints of any of these hard parts, or of insects, leaves, or soft-bodied animals.

Fossils are most abundant in limestone and somewhat less common in shales and sandstones. Marine shells or shell imprints are preserved more often than parts of land animals.

Figure 6-18. Fossils may be preserved in sedimentary rocks: a. fern, b. shells, predominantly *Exogyra*, c. bark of *Sigillaria*.

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Fossils record past life and supply clues to geologic history.

Fossils reveal many things about the past. From this information, a geologist can determine the kinds of plants and animals that lived when a certain rock was being deposited. He can also reach conclusions about the kind of environment in which deposition was made.

Ocean deposition is almost always covering dead sea animals with layers of sediment. Many sea animals have body parts that are readily preserved.

Other clues to the past are found in the sediments themselves. Conglomerates suggest disintegration of a rugged, mountainous land where conditions were not favorable for decomposition. Sandstones suggest transportation by rivers, winds, or waves, and a gradual decrease in velocity accompanied by good sorting. Shales suggest deposition in quiet bodies of water where sorting eliminated all but the finest materials. Sediments that form clays come from lands where decomposition has been almost completed.

M. E. Schroeder

Figure 6-19. Sand blown about by the wind forms asymmetrical ripple marks.

Ripple marks and mud cracks form today as they have in the past. Ripple marks form in shallow water along shore zones and on the surface of sand dunes. Mud cracks form along shores where mud deposits are thoroughly dried out from time to time. Sand, blown or washed into the cracks, preserves them even when they are covered by water.

Concretions (kan kree′shuns) are sedimentary features associated with the upper surface of a rock layer. They are formed from cementing materials precipitated layer upon layer around a central core. Concretions may be less than an inch or many feet in diameter. *Geodes* (jee′ohds) are hollow spherical bodies found commonly in limestone. The outer rim of the geode is hardened silica called *chalcedony* (kal sed′en ee). Clear quartz crystals grow inward from this outer rind. (Figure 6–20.)

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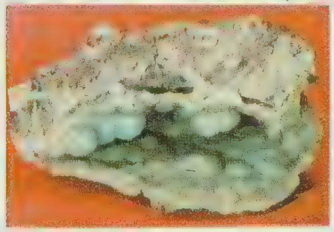

Figure 6-20. Quartz chalcedony mammillary geode.

EXPERIMENT. Put small fragments of limestone, granite, basalt, and quartz in a jar. Fill the jar with water and let it stand overnight. Next day, separate the various materials, putting the pieces of limestone in one jar, granite in a second jar, basalt in a third jar, and quartz in a fourth jar. Add enough 15 percent hydrochloric acid (HCl) to each jar to just cover the pieces, and let them stand overnight.

On the following day, examine the jars and record what has happened to the rocks in each jar. Compare your results with your experiment with clear water. From your experiment, describe the rocks that would be most likely to have caves formed by solution of the rock materials. Review the origin of acids in surface waters in Section 6:4. Would waters in the soil be most likely to be acid in tropical, in temperate, or in arid regions?

Figure 6-21.

Table 6-1. ***Sedimentary Rock***

	Name	*Texture*	*Composition*	*Comments*
CLASTICS	Conglomerate	Round pebbles	Any kind of rock or minerals	Pebbles held together with sand, clay, and cement
	Breccia	Angular pebbles	Any kind of rock or minerals	
	Sandstone	Sand-size grains	Quartz (most common) or feldspar and quartz	Grains may be calcite
	Siltstone	Very fine grains	Mostly quartz, some clay	Gritty feel
	Shale	Microscopic grains and flakes	Mostly clay, some mica	Occurs in layers, no gritty feel
NONCLASTICS	Limestone	Coarse to microscopic crystals	Calcite or microscopic shells	Chalk—microscopic texture, a precipitate or evaporite
	Chert (flint)	Microscopic crystals	Chalcedony	Common as cement in rocks, or as masses, a precipitate
	Alabaster	Microscopic to coarse crystals	Gypsum or anhydrite	Evaporite
	Rock salt	Cubic crystals	Halite	Evaporite
	Peat, lignite, or coal	Coarse to microscopic plant fragments	Products of plant decay in absence of oxygen	Fragments of plants to fine-grained carbon compounds

Figure 6-22. Conglomerate.

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Figure 6-23. Breccia.

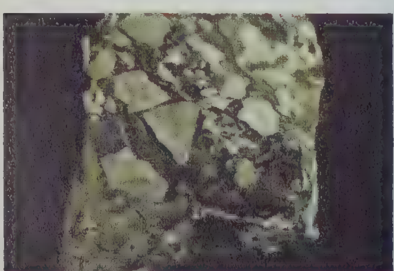

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Figure 6-24. Sandstone (red).

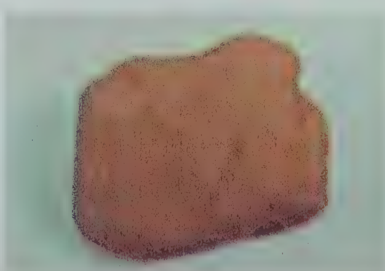

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Figure 6-25. Sandstone (banded).

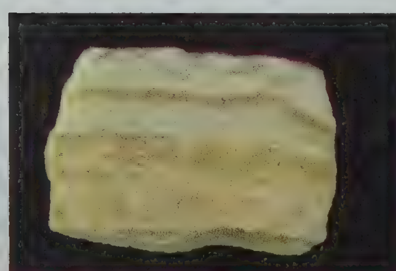

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Figure 6-26. Sandstone (glaunitic).

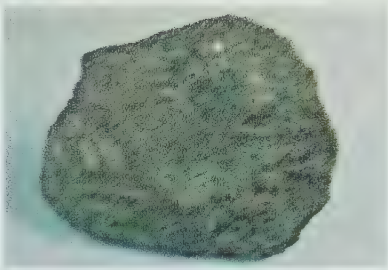

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Figure 6-27. Limestone (massive).

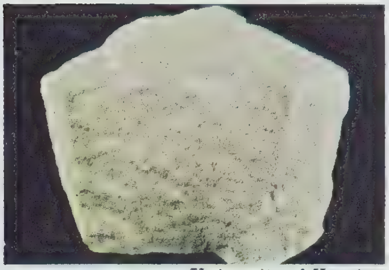

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Figure 6-28. Limestone (crystalline).

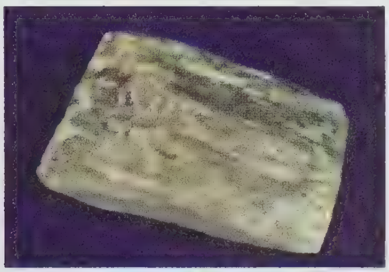

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Figure 6-29. Chert.

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Figure 6-30. Coal.

National Coal Association

MAIN IDEAS

1. Rocks undergo constant change, as they have for billions of years since the earth began.
2. Breaking up of rock at or near the surface, called weathering, may be caused by mechanical or chemical means.
3. Weathering by mechanical means (disintegration) results from weather and climate conditions and the presence of plants, animals, and water.
4. Chemical weathering (decomposition) depends on the presence of water. Water aids the formation of carbonic acid and distributes humic acid from plants and animals. Both acids react with rock materials.
5. Decomposition produces insoluble iron oxide and clay, and silicas and carbonates in soluble form.
6. Weathering produces exfoliated rocks, spheroidal boulders, and both residual and transported soils.
7. Sedimentary rocks are formed when soil grains, fragments of rock, or soluble substances are hardened into solid rock.
8. A type of sedimentary rock, called clastic, is formed of fragments or grains that have been pressed together, or cemented, by silica or calcite.
9. Clastics are named according to the size and shape of the fragments of which they are composed. Clastics include conglomerate or breccia, sandstone, siltstone, shale, and tillite.
10. Nonclastics are formed by chemical and/or organic processes. They include evaporites, precipitates, and organic deposits.
11. Evaporites (calcite, halite, gypsum, and alabaster) are minerals left behind when the water which carried them evaporates. Precipitates (limestone, chert, and some ores) are formed by combinations of chemicals brought into contact by percolating water or in seawater. Organic deposits include limestone reefs and types of mineral fuels.
12. Unless crustal movements have taken place, sedimentary rocks are found in layers, progressing downward from the youngest deposit to the oldest deposit on the bottom.

13. Sedimentary rock records, such as fossils, ripple marks, mud cracks, geodes, and concretions, provide clues to the history of the earth.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

compaction	exfoliation	sediment
conglomerate	fossil	solution
decomposition	permeable	spheroidal
deposition	porous	strata
disintegration	precipitation	suspension
evaporation	residual	weathering

STUDY QUESTIONS

A. True or False

Determine whether each of the following statements is true or false. (Do not write in this book.)

1. Ice wedging is not an important weathering agent in Florida or Texas.
2. The effect of disintegration is more evident in arid climates than in humid climates.
3. Rainwater contains a weak acid.
4. Quartz does not break down into clay.
5. Chalk is a form of limestone.
6. The mantle rock and the inner mantle of the earth are about the same thickness.
7. Soil is a product of advanced weathering of the mantle rock.
8. Granite areas grade downward from residual soil, through mantle rock, to bedrock.
9. The formation of both evaporites and precipitates depends on the presence of water.
10. It is possible for the clastics breccia and conglomerate to have similar compositions.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following statements. (Do not write in this book.)

1. Spheroidal boulders are formed by (*precipitation of cementing material around a nucleus, weathering along joints, consolidation of conglomerates*).
2. Chemical weathering is most important in (*polar, desert, tropical*) areas.
3. Clay and mud are formed from decomposed (*igneous, limestone, sandstone*) rocks.
4. Decomposition is weathering by (*mechanical, chemical, physical*) means.
5. Rocks that contain (*pyroxene, quartz, feldspar*) decompose more slowly than other rocks.
6. The most common rock formed by precipitation is (*alabaster, rock salt, limestone*).
7. The sedimentary rock formed from decay of buried trees and plants is (*coal, chert, limestone*).
8. Hollow spherical bodies found in limestone are called (*exfoliation domes, geodes, spheroidal boulders*).
9. Deposits formed from plants are called (*precipitates, organic, evaporites*).
10. The composition of grains in sandstone is mainly (*quartz, mica, halite*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. __?__ is the breaking up of rock in place, at or near the surface of the earth.
2. Disintegration means that rock is broken down by __?__ means.
3. Plants and animals contribute __?__ acid to the process of decomposition.
4. Thawing and freezing result in weathering called __?__.
5. Sedimentary rocks formed by evaporation or precipitation are called __?__.

6. Air and water are necessary for the weathering called ___?___.
7. Soil which is closely related to the bedrock below it is ___?___ soil.
8. Clastics are hardened into rock by ___?___ and ___?___.
9. Sedimentary layers may contain records of past life called ___?___.
10. Sandstones, shales, conglomerates, and limestones are ideally found in a subsiding basin in the following descending order: ___?___, ___?___, ___?___, and ___?___.

D. How and Why

1. What does James Hutton's term uniformitarianism mean? How does this term apply to sedimentary rocks and to extrusive igneous rocks? Does this term have any meaning in connection with intrusive igneous rocks or with metamorphic rocks?
2. Sedimentary rocks form a thin veneer or cover on the surface of the earth. How does their distribution compare with the distribution of igneous rocks? How does their volume compare with the volume of igneous rocks? Explain why sedimentary rocks are so widespread.
3. Why should ice wedging be more effective in Illinois than in Alaska?
4. How might forest fires contribute to weathering processes?
5. Why is the cover of sediments much thicker in the Mississippi Valley than on the Continental Divide?
6. If you wanted to drill a well to furnish water, would you try to drill to a sandstone or a shale layer? Why?
7. Under what conditions would breccia form rather than conglomerate?
8. Why do cave deposits often occur as large crystals?
9. In what kind of sedimentary rock would you be most likely to find well-preserved fossils? Why?
10. What conditions produce a series of sedimentary layers in which bottom layers are coarse conglomerates, the next layers are sandstones, and the top layer is shale?

INVESTIGATIONS

1. Collect pictures which illustrate types of weathering and prepare a bulletin board display. Include pictures of caves, trees growing out of rocks, cracks in pavement, and so on. Write a short explanation of each example and place it with the illustration. Indicate whether the weathering is disintegration or decomposition.
2. Draw a diagram of the ideal layering of sedimentary rock which has not been disturbed. Indicate in which layer you would expect to find the following: kaolinite, coal, coral, peat, gypsum, mica, breccia, and quartz.

INTERESTING READING

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U. S. Department of Agriculture, *Soil (U.S.D.A. Yearbook, 1957)*. Washington, D.C.: U. S. Government Printing Office, 1957.

White, A. T., *Rocks All Around Us*. New York: Random House, 1959.

Metamorphic Rocks

Metamorphic rocks are the least abundant of the three rock classes. Like sedimentary rocks, the metamorphic rocks are formed by both chemical and mechanical processes. Unlike sedimentary rocks, metamorphic rocks form only at great depths or at high temperatures. Intrusive igneous rocks and metamorphic rocks form in similar environments. Both are unstable and are subject to weathering at the earth's surface.

7:1 *Origin*

Metamorphic rocks are derived from either sedimentary or igneous rocks.

Sedimentary rock and igneous rock may be transformed into metamorphic rock. **Metamorphic rock** is rock that has been changed by great heat and pressure within the crust. Metamorphism occurs at temperatures ranging from 150°C (302°F) to approximately 800°C (1472°F) and at depths of from one mile to several miles. Occasionally, contact with an intruding magma may furnish enough heat for local metamorphism within one mile of the surface. But, in general, metamorphism indicates deep burial.

During metamorphism, the parent rock undergoes a change in composition or in the size and arrangement of the mineral grains. Changes in both composition and texture occur while the rock remains in the solid state. If melting occurs, the rock that forms is called igneous rather than metamorphic. *Migmatites* are rocks that contain alternate layers of igneous and metamorphic rock.

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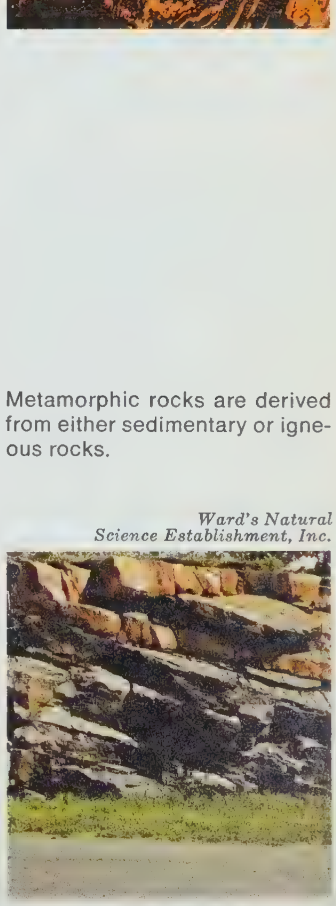


Figure 7-1. Migmatite.

7:2 *Metamorphic Processes*

High heat and great pressure cause metamorphism. Heat may come from the decay of radioactive elements in the mantle, from friction accompanying mountain building, or from hot

Heat originates with radioactive decay of some elements in the mantle.

magma intruded into rock already in place. Of these three, decay of radioactive elements is believed to be the most important source of heat. During decay, radioactive elements spontaneously break down into other new elements. An element changes to another element only when the nucleus of the atom changes. (Section 3:5.) Usually nuclear energy in the form of heat energy is released during the change.

Pressure results from the weight of overlying sediments or from forces associated with mountain building.

Pressure is associated with the uplift of mountains and the intrusion of large igneous masses. Such pressures may cause extensive metamorphic changes. Pressure is also exerted on deeply buried rocks by the weight of overlying material. The weight of overburden does not cause changes in composition, but at depths of several miles, may cause rearrangement of mineral grains.

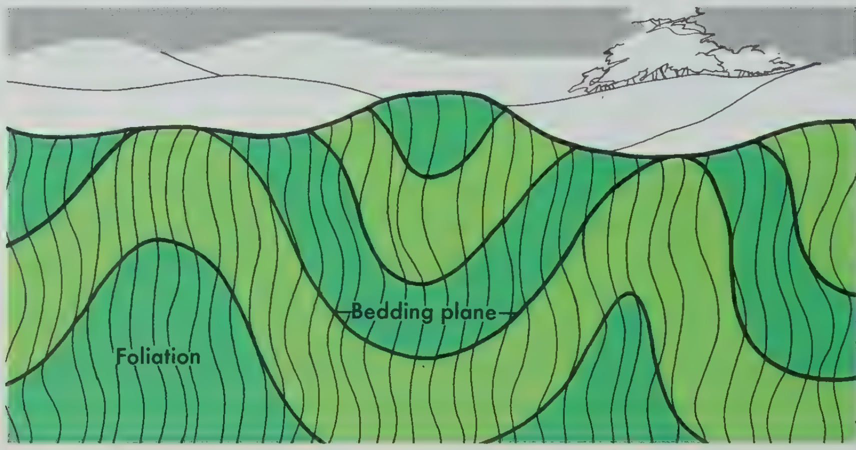


Figure 7-2. Foliation is banding that results from differential pressure applied to rocks after they have been buried and consolidated.

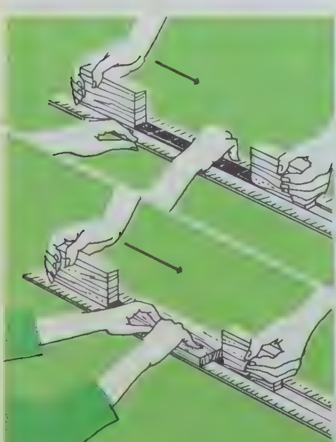


Figure 7-3a.

EXPERIMENT. Arrange several dominoes or toy building bricks end to end. Place yardsticks or smooth flat boards on either side of the blocks to serve as guides. Hold a block of wood firmly at one end of the line of blocks. Push at the other end of the line with a second wooden block. One student should hold the yardsticks while another student pushes the line of blocks. What do the dominoes represent? Why are the yardsticks necessary? What is the source of energy in the experiment? Explain what happens to the dominoes.

Realign the dominoes. Place a short flat board above the dominoes and have another student press downward on the flat board. Repeat the first part of the experiment. Do the dominoes move into a vertical position? What does this indicate about the relative pressures to which rocks are subjected when they show evidence of flowage or rupture?

Try the experiment again, using a slab of clay instead of the dominoes. Next, use a loaf of bread and try pushing against the bread with two wooden blocks. Two students should push against the bread, one from each end.

What observations can you make about the way similar pressures affect different materials? Which type of material would flow more readily under pressure, clay or granite? If you consider only the pressure, would you expect metamorphic changes in clay to occur at a lesser or greater depth than in granite?

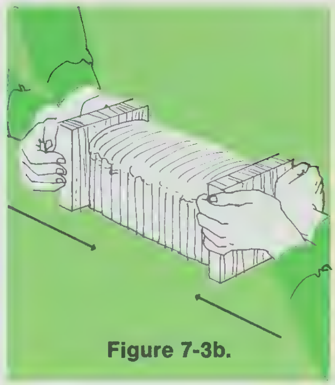
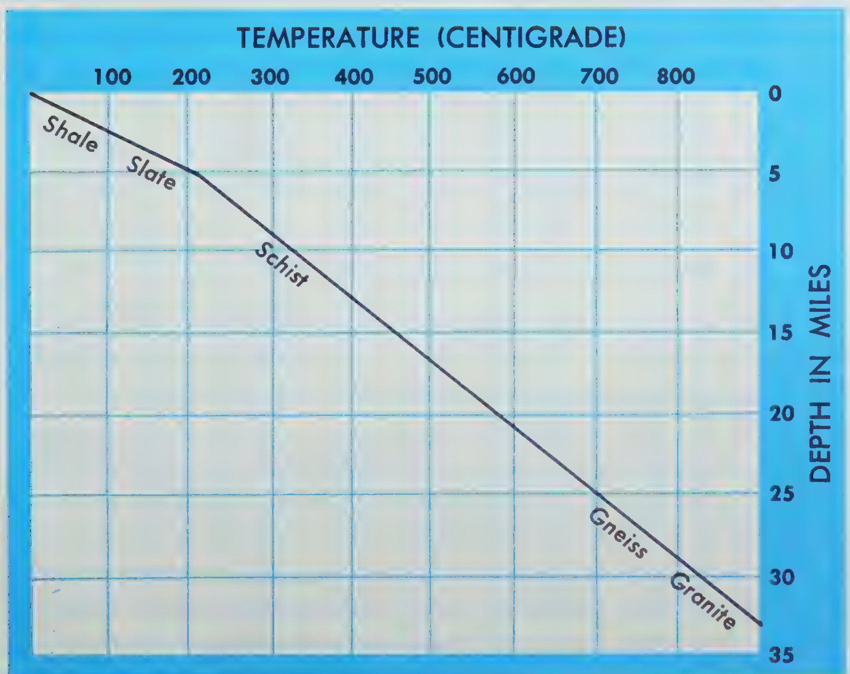


Figure 7-3b.

Thermal (thur′mal) *metamorphism* includes changes due to heat. Although heat is accompanied by pressure, in thermal metamorphism heat determines the kind of metamorphic changes that occur. High temperatures cause a baking effect on the rock, creating a high gloss similar to the glaze on fine china. Enlargement of minerals, or *recrystallization*, is also characteristic of thermal metamorphism. Crystals of fine-grained rocks are enlarged by movements of certain ions from positions of greatest pressure to positions of least pressure. Original minerals are made larger and new minerals are formed, but no new elements are added to the rock and no elements are removed.

Metamorphic processes include thermal, dynamic, and metasomatic changes.

Recrystallization is the enlargement of original mineral crystals and the formation of new mineral crystals during thermal metamorphism.



7-4. As temperature rises with depth, rocks change from sedimentary to metamorphic and eventually to igneous.

EXPERIMENT. Caution: Perform this experiment only under adult supervision. *Determine the effect of heat on minerals under pressure. Put 1 cup of water in a pressure cooker. Place the cooker over heat, and when some steam has escaped, put the pressure gauge on the cooker. Watch the pressure gauge pointer rise to the point marked HIGH. Turn off the heat. What happens to the gauge when the heat is turned off? Explain what occurs within the cooker to make the gauge rise and then fall.*

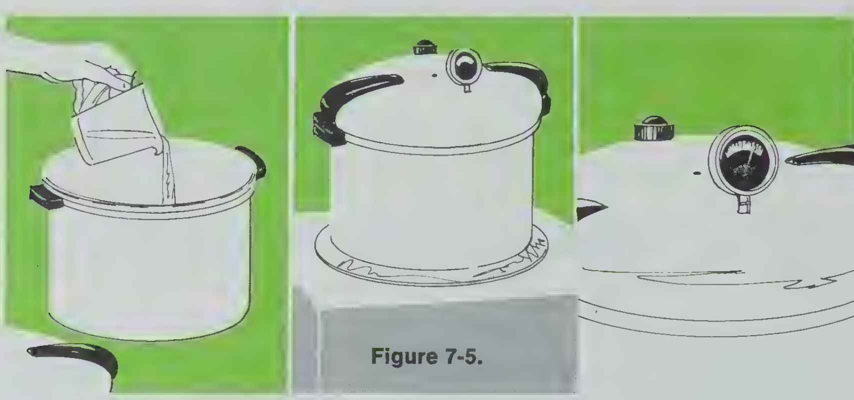


Figure 7-5.

Metasomatism is the growth of new minerals due to an exchange of ions between the original rock and high temperature fluids moving through the rock.

When fluids at high temperatures move through a rock, some ions may be removed from the parent rock. Other ions may be left behind. Many new minerals are formed in metamorphic rocks during this exchange, which is known as *metasomatism* (met e soh′ma tiz um). Some of the new minerals occur only in metamorphic rocks. Some of the new minerals are rare gems, such as rubies and sapphires. Garnets are among the rare minerals typical of metamorphic rocks.

Dynamic (die nam′ik) *metamorphism* includes changes due primarily to pressure. Both temperature and pressure increase with depth, but pressure is the dominant influence except near the core of mountain chains and adjacent to igneous intrusions. Pressure may cause recrystallization and influence the arrangement of mineral grains. Rocks appear to be hard and unyielding at the surface, but under high temperatures and great pressure they become pliable like soft clay. Atoms slide into new positions, and minerals are redistributed to occupy the least possible space. All minerals having one axis longer than the other are realigned like toothpicks in a box. Such changes in mineral arrangement are called *foliation* (foh lee ae′shun).

7:3 Texture

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Figure 7-6. Contorted gneiss.

Texture in metamorphic rock refers to the size, shape, and arrangement of grains. Rocks may be foliated, or recrystallized, or have a combination of the two textures. *Foliated textures* are bands or layers. The bands may be as close together as the pages of a book, or they may be several feet apart. Banding often results from the presence of dark-colored mica and light-colored mica. Micas occur in flakes that tend to line up in nearly parallel layers. Amphiboles also tend to be arranged in parallel bands. Rocks containing mica or amphibole often have dark layers alternating with lighter-colored minerals such as feldspar or quartz.

Recrystallized texture consists of large interlocking crystals. Recrystallization is most common for quartz, calcite, and feldspar. As these minerals increase in size, foliation bands appear farther apart.

Foliation may occur alone or it may occur in combination with recrystallization.

7:4 Composition

Minerals in metamorphic rocks include the same minerals that occur in igneous rocks. But metamorphic rocks also contain certain minerals not found in any other kind of rock.

Metamorphic rocks contain many of the same minerals as igneous rocks.

Shale and sandstone layers contain the same elements as igneous rocks, but the elements are present in different combinations. Feldspars, amphiboles, quartz, and other minerals such as mica are formed from sedimentary rocks during metamorphism. Calcite and quartz recrystallize under pressure regardless of the temperature. Other minerals develop only during thermal metamorphism.

7:5 Metamorphic Rank

Metamorphic intensity, or **rank,** differs from place to place according to the amount of pressure and the temperature. The higher the temperature and pressure, the greater the metamorphic change. Maximum metamorphism occurs close to the center of mountain building, where both temperature and pressure are greatest. The amount of metamorphism gradually decreases with distance from the center of uplift. *Regional metamorphism* is metamorphism that affects a large area. Mountain building usually is accompanied by regional metamorphism.

High rank metamorphism is associated with temperatures of 700°C to 800°C. Low rank metamorphism is associated with temperatures close to 150°C.

Regional metamorphism affects wide areas of mountain building and includes both high and low rank effects.

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Figure 7-7. Abrupt contact between schist and granitic intrusion preserved in a weathered boulder.

Contact metamorphism occurs in narrow zones adjacent to igneous intrusions and includes only high rank effects.

Metasomatic changes and thermal metamorphism are at a maximum in the contact metamorphic zone.

Contact metamorphism occurs when intrusions of hot magma change the rock with which they come in contact. Metasomatic changes are characteristic. The hot magma contains liquids and gases that penetrate the adjacent rock and exchange ions with it. Contact metamorphism may be limited to a few inches, or it may include a zone about one mile wide, depending on the size of the igneous intrusion. The contact zone contains rocks of highest metamorphic rank; that is, rocks which represent the most extreme metamorphism. Temperatures are at a maximum (about 800°C or 1472°F) and rocks are changed both chemically and physically. Rare minerals are common in the contact zone. (Figure 7–7.)

7:6 *Classification*

Metamorphic rocks are grouped into foliated and nonfoliated rocks. **Foliated rocks** include rocks with banding. Examples of foliated rocks are slates, phyllites, schists, and gneisses.

Names are given to foliated rocks according to the width of the layers or bands. As the width between bands increases, recrystallization becomes more important.

Slates usually form from shale, and have extremely fine foliation. Layering is difficult to recognize without the aid of a microscope. Occasionally, if a rock is broken across its foliation, layers can be recognized. Minerals, however, are usually too small to be seen. Slate represents the lowest rank of metamorphism, where temperatures are just high enough (150°C or 302°F) for metamorphism to occur. Slates are formed farthest from the mountain core during regional metamorphism and may form at great depths below the earth's surface due to the weight of the overlying rock.

Phyllites are just one step above the slates in metamorphic rank. Layering is similar to that of slates. Mica flakes are present but are barely visible. Mica gives phyllite a shiny surface which contrasts with the dull surface of slate.

Schists are rocks in which recrystallization has occurred, but these changes were not great enough to eliminate foliation. Instead, layers of dark minerals, such as biotite or amphibole, are separated by lighter-colored minerals of feldspar or quartz. Layers are a fraction of an inch to as much as one inch apart. Recrystallized minerals are large enough to be identified. Schists are given a number of descriptive names, depending on the dominant minerals. If quartz is present, the schist is a quartz schist; if one of the micas dominates, it is a mica schist; if garnets are present, the rock is a garnetiferous (gahr net-if′e rus) schist.

Schists form closer to the mountain core than slates or phyllites do. They make up vast areas of regionally metamorphosed rocks, representing intermediate temperatures of 200°C or 300°C (392°F or 572°F) up to relatively high temperatures of about 700°C (1292°F). Schists are the most common metamorphic rocks and may come from a variety of parent materials such as shale, impure limestone, or even basalts.

Paul W. Nesbit

Figure 7-8. Rocks from the mountain core often contain layers of schist intruded by granitic rock.

Gneiss (nies) is a metamorphic rock that looks like granite. However, gneiss has rough layering of the dark constituents. Either biotite or amphibole may be present in widely separated layers which are inches or even feet apart. Gneiss represents the maximum rank of metamorphism, except for the contact zone. Gneiss occurs in association with the mountain core, and may grade gradually into true igneous granite-type rocks. Gneisses are commonly confused with schists.

Nonfoliated rocks include rocks without banding. Two examples of nonfoliated rocks are marble and quartzite.

Nonfoliated rocks exhibit recrystallization without banding.

Marble is the recrystallized rock which comes from pure limestone. Some limestone and marble are so similar that it is sometimes difficult to tell them apart. However, marble is harder than limestone and the crystals in marble are larger. Marble may be pure white or, when colored by impurities, it may be black, red, yellow, or green.

Quartzite is the recrystallized metamorphic rock derived from quartz sandstone. It is a hard rock with a wide range of colors due to the various colors of iron stain or other impurities. Single-mineral rocks, such as sandstone and limestone, recrystallize without foliation because no contrasting minerals are present to form bands.

Serpentine, also called serpentine marble, is a green crystalline metamorphic rock. Serpentine forms during the alteration of a basalt. Serpentine may be associated with marble. If cut into slabs and polished, it is used as a decorative rock called green marble.

ACTIVITY. Examine several specimens of metamorphic rock. Use your collection of metamorphic rocks and some from the room collection. Classify the rocks into foliated and nonfoliated groups. Assign them names according to the metamorphic rock chart. (Table 7–1.)

Indicate that the rocks are metamorphic by labeling them M *with India ink in a small area of white paint. Place a number after the* M *and write both the number and the name in your notebook. Indicate the possible source rock for each of the specimens. What are the characteristics by which you recognize each rock?*

Put a drop of 15 percent hydrochloric acid (HCl) on each rock, wait for a reaction, and then quickly wipe it off. Record which of the rocks starts bubbling when HCl is dropped on it. Test each rock for hardness. (Table 4–3.) Which rocks cannot be scratched with a knife? Examine the fine-grained rocks with a magnifying glass to see whether you can identify the minerals. What mineral is present in the dark layer of the schist?

Write a paragraph in your notebook telling what similarities and differences you observe between metamorphic rock and igneous rock. Are any of the metamorphic rocks similar to sedimentary rocks?

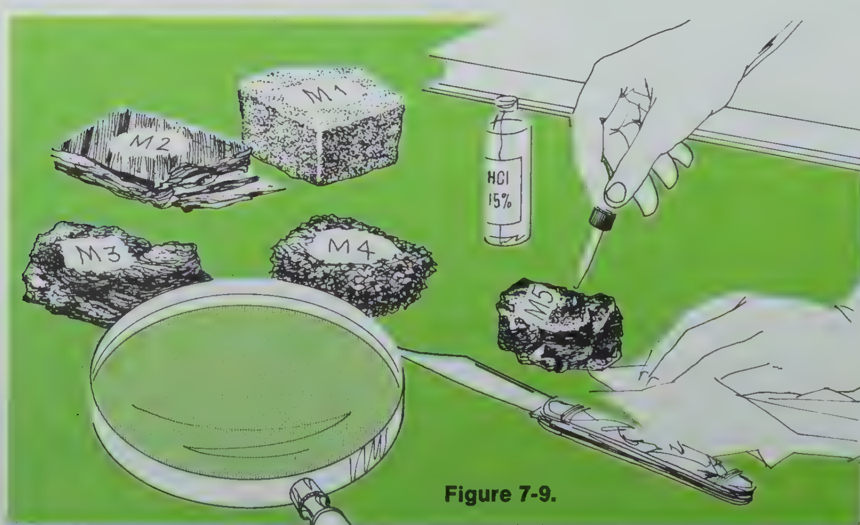

Figure 7-9.

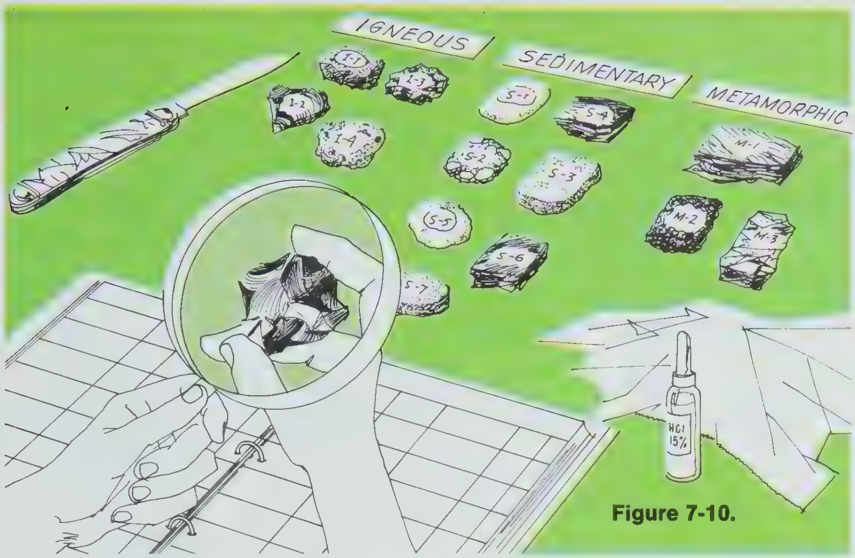

Figure 7-10.

ACTIVITY. *Use a set of identified and labeled rocks. The rocks should include chert, chalcedony, obsidian, granite, conglomerate, chalk, pumice, coal, basalt, slate, limestone, sandstone, gneiss, marble, and shale. Carefully break off a piece of each of the rocks to expose a fresh, unweathered surface. Test the surface with a steel knife for hardness. Put a drop of 15 percent hydrochloric acid on each sample. Examine the rock surface with a magnifying glass. Record your answers to the following questions about the rock samples:*

1. *Which rocks give off bubbles when tested with hydrochloric acid?*
2. *Which rocks have crystals?*
3. *Which rocks feel gritty to the fingers?*
4. *Which rocks have many openings?*
5. *Which rocks have layers?*
6. *Which rocks have a distinct odor?*
7. *Which rocks look like glass?*
8. *Which rocks are made of pebbles?*
9. *Which rocks make a mark on your hand or paper?*
10. *Which rocks may be used in arrowheads?*
11. *Which rocks can you use for writing?*

Classify the rocks into igneous, metamorphic, and sedimentary groups. List each group and its members in your notebook. Compare your unmarked samples with the set of identified and labeled rocks. Examine your unmarked rocks and classify them into the three types. Put a small square of white, waterproof paint on your samples. Use India ink to number each rock to correspond with the number on the known sample. In your notebook, list the number and the name of each rock sample.

Table 7-1. *Metamorphic Rock*

	Texture		*Name*	*Rank*	*Origin*
	Arrangement of Grains	Size of Grains			
FOLIATED	Layers almost invisible	Microscopic	Slate	Lowest	Shale and siltstone
		Microscopic (except for mica flakes)	Phyllite	Low	Shale and siltstone
	Layers visible to ½ in. apart	Recognizable	Schists	Intermediate to high	Extrusive igneous rock; shale, siltstone, impure sandstone, impure limestone
	Layers ½ in. to several feet apart	Easily recognizable	Gneiss	Highest	Intrusive igneous rock; shale, siltstone
NONFOLIATED	No layers	Calcite minerals easily recognizable	Marble	All ranks	Pure limestone
		Quartz minerals easily recognizable	Quartzite	All ranks	Pure sandstone
		Serpentine minerals easily recognizable; occasionally calcite is present	Serpentine	All ranks	Basalt, peridotite

Figure 7-11. Slate.

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Figure 7-12. Schist.

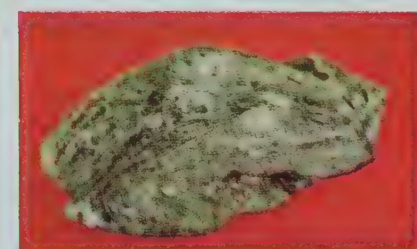

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Figure 7-13. Gneiss.

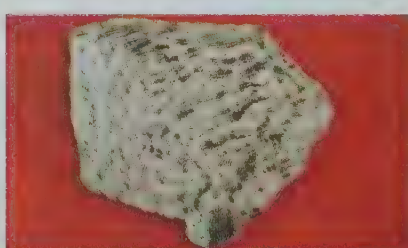

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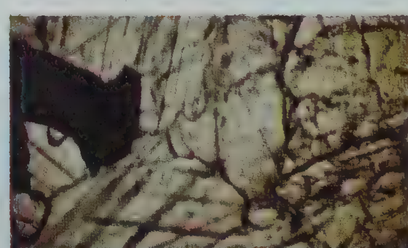
Figure 7-14. Marble (spinel-chrondrodite).



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MAIN IDEAS

1. Metamorphic rocks, which are less abundant than either igneous or sedimentary rocks, are formed at temperatures as high as 800°C and under great pressure while the rocks remain in a solid state.

2. The heat which causes metamorphism is produced by radioactive decay, friction during mountain building, pressure, or intrusions of magma.

3. Pressure is caused by a heavy burden of overlying rocks, crustal movement or uplift, or intruding magma.

4. Thermal metamorphism (metamorphism by heat) may cause rocks to recrystallize or to form new minerals by rearrangement of ions.

5. Igneous intrusions of liquid rock may cause the exchange of ions along points of contact with other rocks (metasomatism).

6. Dynamic metamorphism (metamorphism by pressure) plus heat causes foliation or rearrangement of minerals in layers.

7. Regional metamorphism, which may cover large areas, occurs where mountain building or crustal activity is taking place.

8. Contact metamorphism, the result of igneous intrusions, is of the highest rank.

9. The minerals in metamorphic rocks are the same ones found in igneous rocks with a few rare additions.

10. Metamorphic rocks showing various degrees of metamorphism and foliation are: *slates*, lowest degree of metamorphism and fine foliation; *phyllites*, much like slates only with visible mica flakes; *schists*, with both foliation and recrystallization, moderate metamorphism, often confused with gneisses; *gneiss*, some foliation, and complete recrystallization, high rank metamorphism.

11. Metamorphic rocks which do not show foliation are classified as recrystallized. Nonfoliated rocks include: marble, from limestone; quartzite, from sandstone; serpentine, possibly from basalt.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

contact metamorphism	radioactive elements
dynamic metamorphism	rank
foliation	recrystallization
gneiss	regional metamorphism
metasomatism	schists
migmatites	serpentine
phyllites	slates
quartzite	thermal metamorphism

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. The banding of metamorphic rocks is called foliation.
2. The hardest rocks may become pliable under pressure and high temperatures.
3. Metamorphic rocks closest to a mountain core are slate.
4. Slates are foliated metamorphic rocks.
5. During recrystallization, combinations of atoms adopt new geometric shapes that require less space than the former shape.
6. Gems, such as rubies, are produced during metasomatism.
7. Metamorphic changes are common at the surface of the earth.
8. Low rank metamorphism occurs at temperatures of approximately 800°C.
9. High rank metamorphism is due to pressure alone.
10. Metamorphism does not involve melting.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. A metamorphic rock which closely resembles granite is (*slate, marble, gneiss*).

2. Metamorphism in which pressure is the dominant controlling factor is called (*dynamic, thermal, contact*) metamorphism.
3. The three most common minerals formed during recrystallization are (*mica, calcite, feldspar, amphibole, rubies, quartz, garnets*).
4. Slate is a metamorphic rock derived from (*basalt, sandstone, shale*).
5. The metamorphic rock that forms from limestone is (*gneiss, schist, marble*).
6. Metamorphic rock which contains alternating layers of metamorphic and igneous rock is called a (*geode, gneiss, migmatite*).
7. Phyllites can be differentiated from slates by the presence of (*mica flakes, quartz crystals, wide banding*).
8. Thermal metamorphism includes metamorphic changes due mainly to (*heat, pressure, ion exchange*).
9. A zone of contact metamorphism is associated with (*low rank metamorphism, dynamic metamorphism, metasomatism*).
10. The foliated rock which would be found closest to a mountain core is (*slate, gneiss, schist*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The agents of metamorphism are __?__ and __?__.
2. Regional metamorphism often takes place during periods of __?__.
3. Two precious minerals associated with metamorphic rocks are __?__ and __?__.
4. Textures of metamorphic rocks are either __?__ or __?__.
5. Most minerals in metamorphic rocks are the same as the rock-forming minerals found in __?__ rocks.
6. The enlargement of old minerals and the forming of new ones during metamorphism is called __?__.
7. If new ions are added to the rock, or ions are removed from a rock during metamorphism, the process is called __?__.

8. Marble and quartzite are formed by ___?___.
9. Igneous intrusions may be associated with both pressure and high temperatures. In the vicinity of the intrusion, the effects of ___?___ are most evident.
10. The amount of metamorphism, or degree of change, is called ___?___.

D. How and Why

1. By what simple test can you distinguish between marble and quartzite? Can you use the same test to distinguish between marble and limestone?
2. Why should minerals in both metamorphic and igneous rocks be the same?
3. What is the most important source of heat for metamorphic processes? Is there any relationship between this heat source and pressure?
4. You have not yet studied mountain building, but you have been given some clues in this chapter to the relationship between mountain building and metamorphism. What information has been developed up to this point to indicate that sedimentary rocks may be buried and then uplifted?
5. Sometimes gneiss layering has several feet between bands. If you had a specimen taken from the section between bands, how would you classify the rock?
6. Schists have the greatest variety of minerals of any of the metamorphic rocks. Can you account for the variety? Contrast the origin of a schist with the origin of marble or quartzite.

INVESTIGATIONS

1. Draw a diagram illustrating the cycle of changes which rocks undergo to become sedimentary, metamorphic, and igneous rock. Remember that the cycle does not necessarily follow the same pattern every time.
2. Prepare a report on the quarrying of marble, limestone, slate, or granite.
3. Make a classification chart for metamorphic rocks on the order of those given for igneous and sedimentary rocks. Be sure to use "foliated" and "nonfoliated" as main divisions.

Indicate the parent rock for each metamorphic rock type and show what minerals are present. Use the igneous chart (Table 5–3) and the sedimentary chart (Table 6–1) to identify the minerals.

INTERESTING READING

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Products of the Lithosphere

During the Stone Age, most of the weapons and tools which were available were made of stone. Since those days, innumerable tools and weapons have been designed. But, like the stone objects, all of them have come from minerals or rocks found in the earth's crust.

8:1 *Utilization*

Early man did not attempt to classify the kind of rock he picked up. He was more concerned with its usefulness. By accident or by trial and error, man found that he could chip certain rocks to make a sharp edge that was useful for cutting and scraping. *Chert,* also called *flint,* could be made with the best edge and became the first eagerly sought industrial mineral. Indians traveled to Ohio and Texas to find the right kind of chert for their arrowheads.

During the Stone Age, weapons and tools were made of flint, chert, or any ordinary stone found on the earth's surface.

Later, man discovered that rubbing flint against a fine-grained sandstone would produce an even sharper edge. Thus, he discovered another industrial mineral, the grindstone. *Fine-grained sandstone* is still in demand as a grinding tool.

During the Stone Age, man discovered that he could store and preserve food in a container. He experimented with clay and learned to make pottery. Thus, he added *clay* to the economic products of the time.

The Bronze Age began when man discovered how to make weapons and tools of copper or combinations of copper and tin.

The Bronze Age began when man discovered *copper* and *tin.* Bronze is a mixture of tin and copper which is harder than copper alone. However, in many areas that had copper, there was no tin. In these regions, man had to use copper alone for tools, weapons, and ornaments.

Next, man discovered how to use *iron.* Because iron is not naturally soft and malleable like copper, iron must be melted

and treated while hot to make it usable. Minerals which contain iron are plentiful and widely distributed. Man learned to extract iron from its ores hundreds of years before the birth of Christ. Probably, primitive man discovered metallic iron when he built great fires against the banks of red rock containing hematite. (Table 4–5.) The heat and gases of the fire may have released iron from its combination with oxygen in hematite (Fe_2O_3), and the metal remained in the ashes of the fire. Man learned that he could shape the newly discovered metal while it was still white-hot. By repeated heating and pounding, impurities were released, and its particles were bound tightly together. Man had discovered a hard, strong material in the charcoal ashes. Thus, the Iron Age began.

The Iron Age began when primitive man learned that iron could be shaped while it was white hot.

At first, iron was considered so precious that its use was limited to rings and ornaments. However, man soon found many other ways to utilize this new material. For example, he made chariot wheels of iron, and he used iron in the construction of Solomon's temple. Steel is one of today's products which is made of iron. It is nearly impossible to imagine life without the steel industry. Iron is still the major industrial and economic metal in the world, although the present time is often called the Atomic Age. During World War II, man first learned to use the energy in the nucleus of the metal uranium. Today, uranium is used as a source of energy, mainly in the production of electricity.

Modern civilization depends on a wide variety of metallic and nonmetallic minerals.

Figure 8-1. Rocks and minerals have both functional and aesthetic uses: a. carved bowls (top row, l to r) lapis, amazonite, agate (bottom row, l to r) rhodonite, malachite; b. hand ax of igneous rock.

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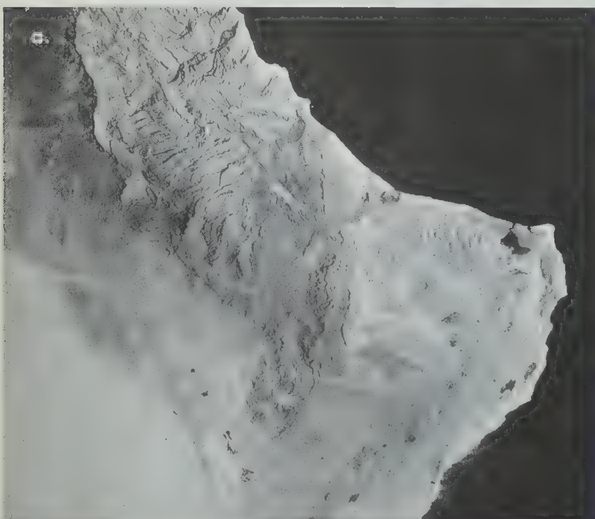
8:2 Ores

Chert, clay, copper, and iron are products of the lithosphere that were readily available to early man. These products are still among the most abundant and useful materials of the lithosphere. However, in the thousands of years since the discovery of iron, many other minerals have become important and useful. Our world has changed greatly from the days of the Stone Age, largely because man has learned to use a variety of metals.

Ores are metallic or nonmetallic minerals which can be mined at a profit.

Minerals or groups of minerals that can be mined at a profit are called **ores.** Originally the term ore was limited to minerals containing metals. Today, the term includes both metallic and nonmetallic minerals that have economic use. Only those minerals that contain a sufficiently large amount of the useful product are classed as ores. In general, mining and treating of ores yields a relatively small amount of the valuable product compared to the amount of valueless rock that must be handled. For example, one ton of ore may yield only four pounds of copper. Copper ores also may contain other metals, such as gold. The Utah Copper Mine at Bingham, Utah, recovers about 35 cents worth of gold from one ton of copper ore. If the rock contains less than 35 cents worth of gold per ton, it is too low grade to be mined for gold. Low grade deposits may become ores if the price of the valuable metal increases enough, or if more efficient mining and treating methods make it profitable to work low grade deposits.

Figure 8-2. Photos taken from spacecraft aid the geologist in his mapping of terrain and furnish clues to favorable areas for further exploration: a. Arabian Peninsula from distance of 120 miles, b. companion geologic map showing surface rocks in the same area as the photo.



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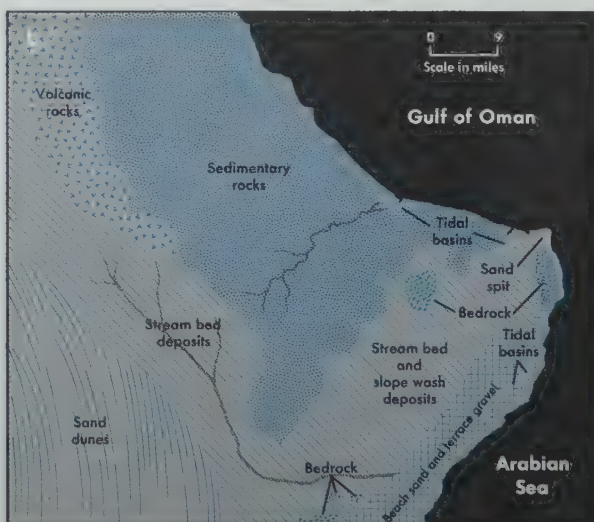

Valuable ores are almost always mixed with lower grade mineral deposits and waste rock. During mining operations, these useless minerals and rock are brought to the surface along with the ore. The waste rock, or *gangue* (gang), is removed by crushing and treating. The concentrated ore then is smelted and refined to eliminate all substances except the valuable, wanted product. The smelting process consists mainly of chemical treatment to remove sulfur, oxygen, and other impurities.

Gangue is the low-grade mineral and waste rock removed with an ore during mining.

8:3 *Metals*

Metals are heavy elements that are *malleable* (mal′ee a bl); that is, they can be shaped by pounding without a loss in strength. Metals differ from one another in many of their properties, but all metals are malleable to some degree. Metals also are *conductors of electricity*, and some metals are especially useful because of this property.

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Figure 8-3. Large gold nugget 1½ inches long.

In most ores, metallic elements occur in combination with oxygen, sulfur, or carbon and oxygen. Copper, gold, tin, and occasionally silver occur as *native metals*; that is, the element is in an uncombined form. Both native metals and metals which are combined with sulfur tend to have metallic luster. Metals in other combinations may have nonmetallic luster.

Most metallic ores occur in regions of igneous rock. Mountainous regions, and areas where mountains have been present but now are worn down, are the most favorable locations for prospecting for metallic ores. Metallic elements are present in the gases and liquids that rise to the top of a magma. You can picture the cooking of a thick pudding as magma. Steam rises and bursts the surface in big bubbles as it escapes. Like the steam in a pudding, fluids rise to the top of the magma and escape into the surrounding rock openings. The fluids cool as they invade the country rock openings, and the contained minerals crystallize from the escaping fluids. Thus, ores are common near the top of an igneous intrusion such as a batholith. Ores also may be present as *veins*, or fillings of former openings. (Figure 8–5.) Often, ore bodies are so numerous that they resemble the branching blood veins of the human body. However, some ore veins are too narrow or too short to be worked profitably. In some veins, metals occur in combination with other elements that cannot be removed profitably. All veins contain

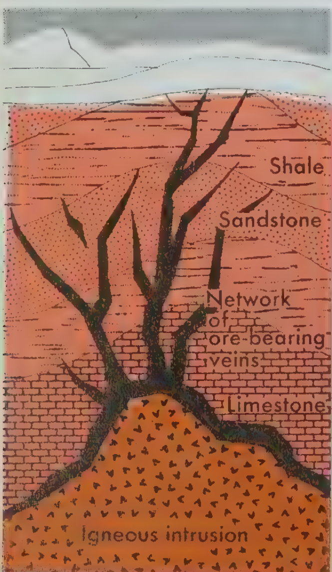
Metallic ore bodies are most common in regions of igneous intrusions.

Figure 8-4. The low density rocks that occur with gold placers may be floated away, leaving the heavier gold on the bottom of the sluice box.

gangue. The most common gangue minerals are quartz and calcite.

Once they are deposited, some metallic deposits remain unchanged. Other deposits are near enough to the surface to be affected by weathering. Copper ores often are concentrated into richer deposits by percolating waters. Copper sulfides are insoluble, but when they are changed to copper sulfates by chemical reactions in the zone of weathering, they may be dissolved. The copper sulfates are carried downward in solution, and, at some depth, undergo other chemical reactions which change them into copper sulfides once more. The sulfides then precipitate from solution and are added to the copper sulfides which have not undergone weathering. In this way, the amount of copper in the vein is increased, and the deposit becomes more concentrated.

Figure 8-5. Gases and liquids from the magma follow cracks in the country rock where they are consolidated to form veins. Veins often are ore-bearing.



Like copper ores, the great iron deposits of North America also have been concentrated by weathering. But unlike copper deposits, the unwanted substances were removed, leaving the iron behind. Iron ores were exposed at the surface of the earth for millions of years. Rocks containing the iron ores were weathered. Clay and silica were carried away, and the iron deposits were enriched as the worthless material was removed.

Gold is another metal which is concentrated into profitable deposits by weathering and erosion. Discovery in 1848 of sedimentary gold deposits, called *placers* (plas′erz), influenced the

great westward migration in the United States in 1849. Originally, the gold occurred in veins high in the California mountains. Weathering caused the rocks containing the veins to crumble. Streams flowing down the mountainsides carried gold grains and nuggets, along with rock fragments, to the foot of the mountains. When the streams reached the foot of the mountains, their velocity decreased. As streams lost their velocity, they lost their ability to carry much of the material picked up in the mountains. Gold was deposited along with sand and gravel in the stream beds. Miners came and panned the gravels to separate them from the gold. Many prospectors followed streams up to the mountain tops to find the original veins from which the gold had been weathered. The great Mother Lode vein in California was discovered in this way. Many veins, however, had been completely eroded away, and all of the gold had been carried down to the foot of the mountains.

Placer deposits are found along stream beds where minerals of high density have been deposited with sand and gravel as the stream's velocity decreases.

Tin, iron, platinum, and even diamonds have been found in riverbeds and along shores as placer deposits. Metals that are heavy tend to be left in riverbeds or along shores where water has carried away the finer, less dense sediments.

Lead, zinc, copper, and many other metallic ores do not occur as placer deposits. These ores occur in veins, or as masses within country rock, and they must be mined by means of shafts driven into the rock or from great open pits.

The Anaconda Company

Figure 8-6. Ores that occur near the surface are mined in open pits from which the overlying soil has been removed. Great quantities of rock are carried away as the mine is deepened.

8:4 Nonmetals

Nonmetals are products of the lithosphere that do not contain metal. They include many products that have no common characteristics.

Nonmetals are also called industrial minerals. **Nonmetals** include such a wide variety of products from the lithosphere that, unlike metals, they have few common characteristics. Industrial minerals include building stones, clay, limestone, fertilizers, and the source rock for many chemical products. Many industrial minerals are widely distributed and relatively abundant. Because so many of the nonmetals are used every day, they seldom are regarded as valuable economic products. Sand is used in making glass and cement. Lime is used in cement, as fertilizer, and in hundreds of other common products. Gravel is used for roads. Sandstone, limestone, granite, marble, and serpentine are all useful as building materials. Table salt comes from halite. Graphite is a component of pencil lead. Potash, nitrates, and phosphates are used in commercial fertilizers. Sulfur is used to manufacture sulfuric acid. Fluorite yields fluorine. Sodium compounds play a part in the preparing, processing, or manufacturing of many of the things you eat, drink, or touch. The list of industrial products from the crust of the earth is almost endless.

Figure 8-7. Salt is an industrial mineral which may be mined or dissolved and brought to the surface as a brine from which salt is then precipitated.

Caterpillar Tractor Company

Texas Gulf Sulphur Company

Figure 8-8. Much of the sulfur in the United States comes from salt domes of the Gulf Coast region. The sulfur occurs with anhydrite and calcite forming a hard layer called caprock above the salt.

Sulfur alone has thousands of uses, and the number constantly increases. Sulfur is used in dyes, fertilizers, pharmaceuticals, rubber, and in iron and steel. The amount of sulfur used by a nation is said to indicate that nation's industrial activity. The United States leads all other nations in the consumption of sulfur.

Sulfur is a source for many products and an index to the industrial activity of a nation.

Gems are products of the lithosphere that are used for decoration. Gems must have beauty, durability, and rarity to be regarded as desirable. Of the more than 2,000 known minerals, only about 80 have the attributes required of gems. From the beginning of recorded history, and probably even before, certain crystalline minerals have been highly prized. The most desirable gems are called *precious stones;* gems that are less rare and less costly are called *semiprecious stones.*

Gems are valuable because of beauty, durability, and rarity.

Precious stones in ancient Egypt, India, and China attracted trade from Europe. Probably the desire for gems, as well as spices, was responsible for the opening of early trade routes between China, India, and Europe.The Incas of the New World had stores of emeralds, diamonds, amethysts, and other precious and semiprecious stones in their temples. Gems never seem to lose their value and desirability. Men have fought and died trying to obtain them. Yet gems are valuable only because of their appeal to a sense of beauty. Greatest values are attached to gems that are rare, free from defects, and perfectly cut. Diamonds, emeralds, rubies, and sapphires continue to be the most highly prized gems.

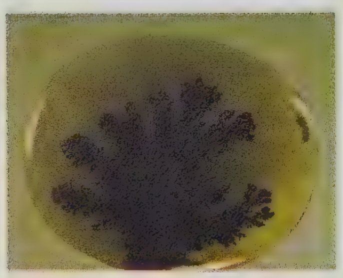


Figure 8-9. Cabochon of quartz with arborescent moss agate pattern.

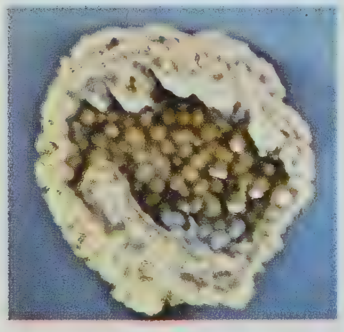


Figure 8-10. Half of large geode of chalcedony.

Photos From Ward's National Science Establishment, Inc.

Figure 8-11. A 93 carat cut yellow sapphire gem.

Semiprecious stones, although not as valuable as precious gems, are very popular. Many varieties of crystalline quartz—including citrine (yellow), amethyst (purple), rose quartz (pink), and colorless quartz—are cut, polished, and mounted to make jewelry. *Agate*, the banded quartz, and *chalcedony* (kal sed′en ee), the colored microcrystalline variety of quartz, are in great demand. The golden variety of *topaz*, a crystalline mineral, is highly prized. *Opals*, especially those known as fire opals, rank close to the precious gems. In the past, opals were believed to bring bad luck. Today, this superstition has largely disappeared and opals are in great demand because of their beauty .

Most gems are silicates. This group includes emerald, tourmaline, topaz, and quartz. Oxides, the next largest group of gems, includes ruby and sapphire. Diamond is made of the element carbon.

Amorphous, or cryptocrystalline gem materials, are commonly cut and polished into a smooth, convex form called *cabochons* (kab′a shahns). First the gem is sawed into a small slab. Then it is ground into the desired shape, sanded, and finally polished. Gem materials of least value are often tumbled with a polishing material in a container. Irregular shapes, called *baroques* (ba rohks′), are formed by tumbling. Transparent, crystalline gems such as diamonds are usually *faceted* (fas′et ed), or cut into smooth, plane surfaces. Gems should have a hardness of 7 or above in order to be cut. Facet cutting is an art in which gems are cut into many small faces. Some gems have as many as 104 faces, cut and polished to reflect and refract light and thus give the crystal a brilliant appearance.

8:5 *Mineral Fuels*

Metals and nonmetals may be found in any kind of rock. Mineral fuels are almost always found in sedimentary rock. Mineral fuels are products of organic decay in the absence of oxygen. The usual environment for the forming of fuels is a swamp or deep hole on the sea bottom, away from sunlight and scavengers. *Scavengers* (skav′in jers) are animals that live on dead matter and, thus, destroy it. Wave action also prevents the preservation of organic matter by breaking it up and allowing it to combine with oxygen. Organic matter contains the elements carbon, hydrogen, oxygen, and nitrogen. If decay occurs

Ripple marks and mud cracks form today as they have in the past. Ripple marks form in shallow water along shore zones and on the surface of sand dunes. Mud cracks form along shores where mud deposits are thoroughly dried out from time to time. Sand, blown or washed into the cracks, preserves them even when they are covered by water.

Concretions (kan kree′shuns) are sedimentary features associated with the upper surface of a rock layer. They are formed from cementing materials precipitated layer upon layer around a central core. Concretions may be less than an inch or many feet in diameter. *Geodes* (jee′ohds) are hollow spherical bodies found commonly in limestone. The outer rim of the geode is hardened silica called *chalcedony* (kal sed′en ee). Clear quartz crystals grow inward from this outer rind. (Figure 6–20.)

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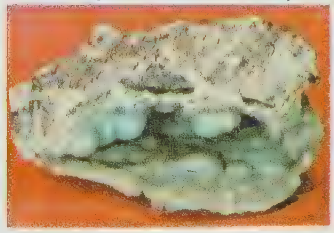

Figure 6-20. Quartz chalcedony mammillary geode.

EXPERIMENT. Put small fragments of limestone, granite, basalt, and quartz in a jar. Fill the jar with water and let it stand overnight. Next day, separate the various materials, putting the pieces of limestone in one jar, granite in a second jar, basalt in a third jar, and quartz in a fourth jar. Add enough 15 percent hydrochloric acid (HCl) to each jar to just cover the pieces, and let them stand overnight.

On the following day, examine the jars and record what has happened to the rocks in each jar. Compare your results with your experiment with clear water. From your experiment, describe the rocks that would be most likely to have caves formed by solution of the rock materials. Review the origin of acids in surface waters in Section 6:4. Would waters in the soil be most likely to be acid in tropical, in temperate, or in arid regions?

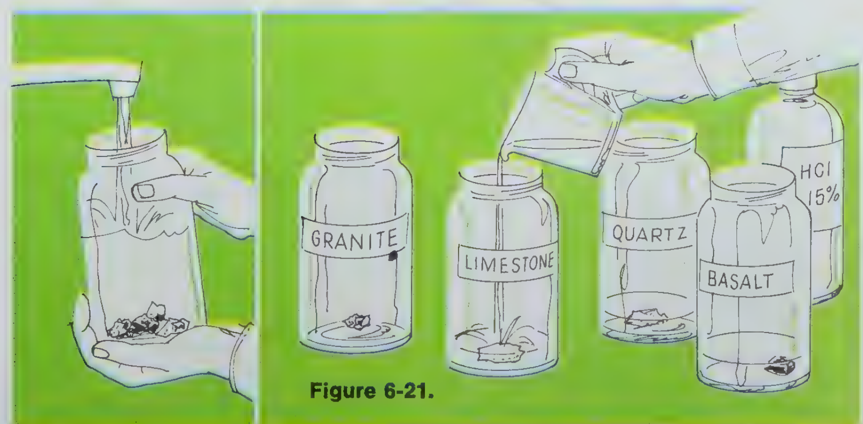

Figure 6-21.

Table 6-1. *Sedimentary Rock*

	Name	*Texture*	*Composition*	*Comments*
CLASTICS	Conglomerate	Round pebbles	Any kind of rock or minerals	Pebbles held together with sand, clay, and cement
	Breccia	Angular pebbles	Any kind of rock or minerals	
	Sandstone	Sand-size grains	Quartz (most common) or feldspar and quartz	Grains may be calcite
	Siltstone	Very fine grains	Mostly quartz, some clay	Gritty feel
	Shale	Microscopic grains and flakes	Mostly clay, some mica	Occurs in layers, no gritty feel
NONCLASTICS	Limestone	Coarse to microscopic crystals	Calcite or microscopic shells	Chalk—microscopic texture, a precipitate or evaporite
	Chert (flint)	Microscopic crystals	Chalcedony	Common as cement in rocks, or as masses, a precipitate
	Alabaster	Microscopic to coarse crystals	Gypsum or anhydrite	Evaporite
	Rock salt	Cubic crystals	Halite	Evaporite
	Peat, lignite, or coal	Coarse to microscopic plant fragments	Products of plant decay in absence of oxygen	Fragments of plants to fine-grained carbon compounds

Figure 6-22. Conglomerate.

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Figure 6-23. Breccia.

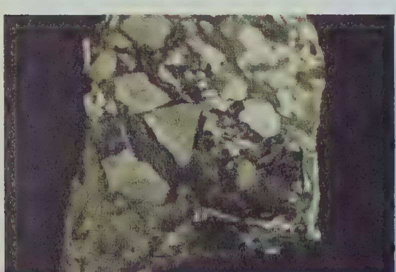

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Figure 6-24. Sandstone (red).

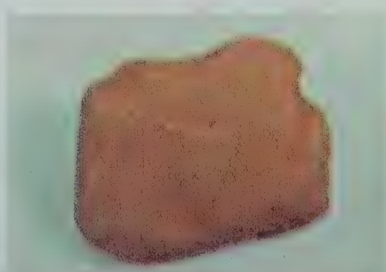

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Figure 6-25. Sandstone (banded).

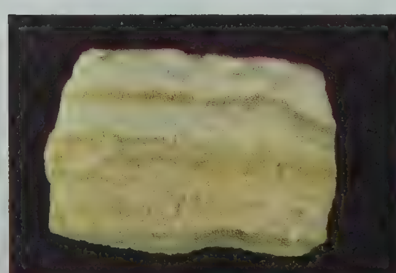

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Figure 6-26. Sandstone (glaunitic).

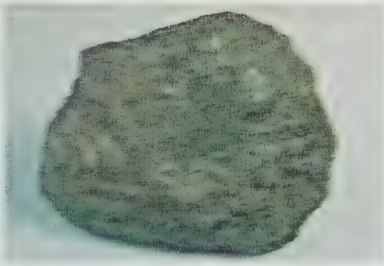

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Figure 6-27. Limestone (massive).

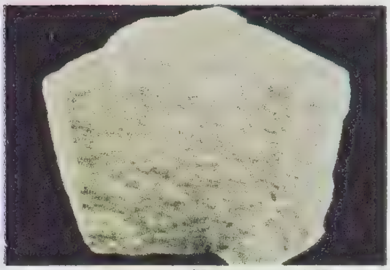

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Figure 6-28. Limestone (crystalline).

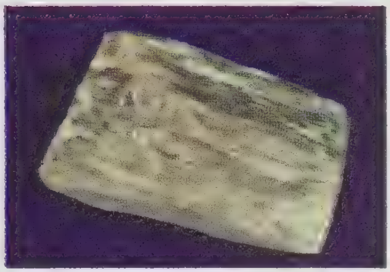

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Figure 6-29. Chert.

University of Houston

Figure 6-30. Coal.

National Coal Association

MAIN IDEAS

1. Rocks undergo constant change, as they have for billions of years since the earth began.
2. Breaking up of rock at or near the surface, called weathering, may be caused by mechanical or chemical means.
3. Weathering by mechanical means (disintegration) results from weather and climate conditions and the presence of plants, animals, and water.
4. Chemical weathering (decomposition) depends on the presence of water. Water aids the formation of carbonic acid and distributes humic acid from plants and animals. Both acids react with rock materials.
5. Decomposition produces insoluble iron oxide and clay, and silicas and carbonates in soluble form.
6. Weathering produces exfoliated rocks, spheroidal boulders, and both residual and transported soils.
7. Sedimentary rocks are formed when soil grains, fragments of rock, or soluble substances are hardened into solid rock.
8. A type of sedimentary rock, called clastic, is formed of fragments or grains that have been pressed together, or cemented, by silica or calcite.
9. Clastics are named according to the size and shape of the fragments of which they are composed. Clastics include conglomerate or breccia, sandstone, siltstone, shale, and tillite.
10. Nonclastics are formed by chemical and/or organic processes. They include evaporites, precipitates, and organic deposits.
11. Evaporites (calcite, halite, gypsum, and alabaster) are minerals left behind when the water which carried them evaporates. Precipitates (limestone, chert, and some ores) are formed by combinations of chemicals brought into contact by percolating water or in seawater. Organic deposits include limestone reefs and types of mineral fuels.
12. Unless crustal movements have taken place, sedimentary rocks are found in layers, progressing downward from the youngest deposit to the oldest deposit on the bottom.

13. Sedimentary rock records, such as fossils, ripple marks, mud cracks, geodes, and concretions, provide clues to the history of the earth.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

compaction	exfoliation	sediment
conglomerate	fossil	solution
decomposition	permeable	spheroidal
deposition	porous	strata
disintegration	precipitation	suspension
evaporation	residual	weathering

STUDY QUESTIONS

A. True or False

Determine whether each of the following statements is true or false. (Do not write in this book.)

1. Ice wedging is not an important weathering agent in Florida or Texas.
2. The effect of disintegration is more evident in arid climates than in humid climates.
3. Rainwater contains a weak acid.
4. Quartz does not break down into clay.
5. Chalk is a form of limestone.
6. The mantle rock and the inner mantle of the earth are about the same thickness.
7. Soil is a product of advanced weathering of the mantle rock.
8. Granite areas grade downward from residual soil, through mantle rock, to bedrock.
9. The formation of both evaporites and precipitates depends on the presence of water.
10. It is possible for the clastics breccia and conglomerate to have similar compositions.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following statements. (Do not write in this book.)

1. Spheroidal boulders are formed by (*precipitation of cementing material around a nucleus, weathering along joints, consolidation of conglomerates*).
2. Chemical weathering is most important in (*polar, desert, tropical*) areas.
3. Clay and mud are formed from decomposed (*igneous, limestone, sandstone*) rocks.
4. Decomposition is weathering by (*mechanical, chemical, physical*) means.
5. Rocks that contain (*pyroxene, quartz, feldspar*) decompose more slowly than other rocks.
6. The most common rock formed by precipitation is (*alabaster, rock salt, limestone*).
7. The sedimentary rock formed from decay of buried trees and plants is (*coal, chert, limestone*).
8. Hollow spherical bodies found in limestone are called (*exfoliation domes, geodes, spheroidal boulders*).
9. Deposits formed from plants are called (*precipitates, organic, evaporites*).
10. The composition of grains in sandstone is mainly (*quartz, mica, halite*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. ___?___ is the breaking up of rock in place, at or near the surface of the earth.
2. Disintegration means that rock is broken down by ___?___ means.
3. Plants and animals contribute ___?___ acid to the process of decomposition.
4. Thawing and freezing result in weathering called ___?___.
5. Sedimentary rocks formed by evaporation or precipitation are called ___?___.

6. Air and water are necessary for the weathering called __?__.
7. Soil which is closely related to the bedrock below it is __?__ soil.
8. Clastics are hardened into rock by __?__ and __?__.
9. Sedimentary layers may contain records of past life called __?__.
10. Sandstones, shales, conglomerates, and limestones are ideally found in a subsiding basin in the following descending order: __?__, __?__, __?__, and __?__.

D. How and Why

1. What does James Hutton's term uniformitarianism mean? How does this term apply to sedimentary rocks and to extrusive igneous rocks? Does this term have any meaning in connection with intrusive igneous rocks or with metamorphic rocks?
2. Sedimentary rocks form a thin veneer or cover on the surface of the earth. How does their distribution compare with the distribution of igneous rocks? How does their volume compare with the volume of igneous rocks? Explain why sedimentary rocks are so widespread.
3. Why should ice wedging be more effective in Illinois than in Alaska?
4. How might forest fires contribute to weathering processes?
5. Why is the cover of sediments much thicker in the Mississippi Valley than on the Continental Divide?
6. If you wanted to drill a well to furnish water, would you try to drill to a sandstone or a shale layer? Why?
7. Under what conditions would breccia form rather than conglomerate?
8. Why do cave deposits often occur as large crystals?
9. In what kind of sedimentary rock would you be most likely to find well-preserved fossils? Why?
10. What conditions produce a series of sedimentary layers in which bottom layers are coarse conglomerates, the next layers are sandstones, and the top layer is shale?

INVESTIGATIONS

1. Collect pictures which illustrate types of weathering and prepare a bulletin board display. Include pictures of caves, trees growing out of rocks, cracks in pavement, and so on. Write a short explanation of each example and place it with the illustration. Indicate whether the weathering is disintegration or decomposition.
2. Draw a diagram of the ideal layering of sedimentary rock which has not been disturbed. Indicate in which layer you would expect to find the following: kaolinite, coal, coral, peat, gypsum, mica, breccia, and quartz.

INTERESTING READING

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U. S. Department of Agriculture, *Soil (U.S.D.A. Yearbook, 1957)*. Washington, D.C.: U. S. Government Printing Office, 1957.

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Metamorphic Rocks

Metamorphic rocks are the least abundant of the three rock classes. Like sedimentary rocks, the metamorphic rocks are formed by both chemical and mechanical processes. Unlike sedimentary rocks, metamorphic rocks form only at great depths or at high temperatures. Intrusive igneous rocks and metamorphic rocks form in similar environments. Both are unstable and are subject to weathering at the earth's surface.

7:1 *Origin*

Metamorphic rocks are derived from either sedimentary or igneous rocks.

Sedimentary rock and igneous rock may be transformed into metamorphic rock. **Metamorphic rock** is rock that has been changed by great heat and pressure within the crust. Metamorphism occurs at temperatures ranging from 150°C (302°F) to approximately 800°C (1472°F) and at depths of from one mile to several miles. Occasionally, contact with an intruding magma may furnish enough heat for local metamorphism within one mile of the surface. But, in general, metamorphism indicates deep burial.

During metamorphism, the parent rock undergoes a change in composition or in the size and arrangement of the mineral grains. Changes in both composition and texture occur while the rock remains in the solid state. If melting occurs, the rock that forms is called igneous rather than metamorphic. *Migmatites* are rocks that contain alternate layers of igneous and metamorphic rock.

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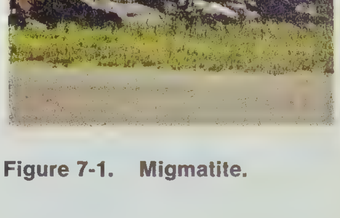


Figure 7-1. Migmatite.

7:2 *Metamorphic Processes*

High heat and great pressure cause metamorphism. Heat may come from the decay of radioactive elements in the mantle, from friction accompanying mountain building, or from hot

Heat originates with radioactive decay of some elements in the mantle.

magma intruded into rock already in place. Of these three, decay of radioactive elements is believed to be the most important source of heat. During decay, radioactive elements spontaneously break down into other new elements. An element changes to another element only when the nucleus of the atom changes. (Section 3:5.) Usually nuclear energy in the form of heat energy is released during the change.

Pressure results from the weight of overlying sediments or from forces associated with mountain building.

Pressure is associated with the uplift of mountains and the intrusion of large igneous masses. Such pressures may cause extensive metamorphic changes. Pressure is also exerted on deeply buried rocks by the weight of overlying material. The weight of overburden does not cause changes in composition, but at depths of several miles, may cause rearrangement of mineral grains.

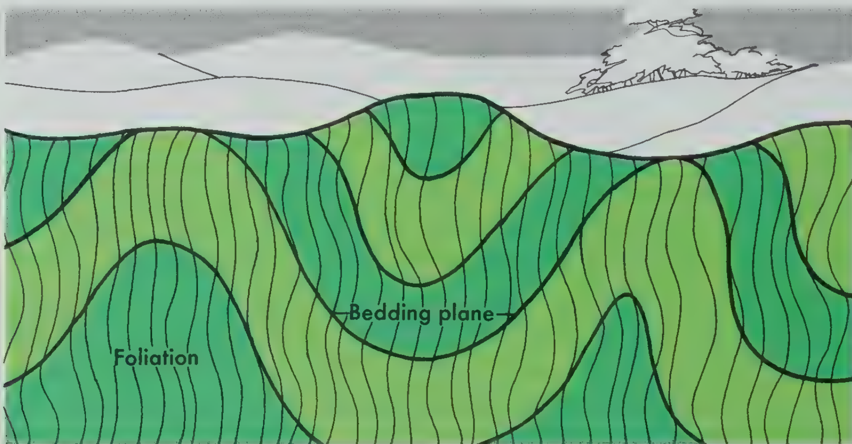


Figure 7-2. Foliation is banding that results from differential pressure applied to rocks after they have been buried and consolidated.

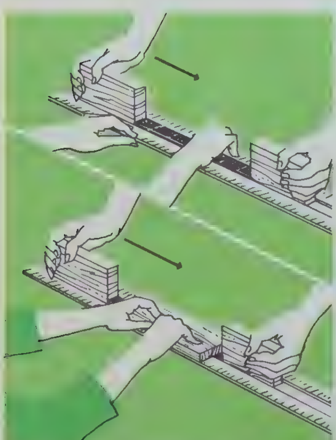


Figure 7-3a.

EXPERIMENT. Arrange several dominoes or toy building bricks end to end. Place yardsticks or smooth flat boards on either side of the blocks to serve as guides. Hold a block of wood firmly at one end of the line of blocks. Push at the other end of the line with a second wooden block. One student should hold the yardsticks while another student pushes the line of blocks. What do the dominoes represent? Why are the yardsticks necessary? What is the source of energy in the experiment? Explain what happens to the dominoes.

Realign the dominoes. Place a short flat board above the dominoes and have another student press downward on the flat board. Repeat the first part of the experiment. Do the dominoes move into a vertical position? What does this indicate about the relative pressures to which rocks are subjected when they show evidence of flowage or rupture?

Try the experiment again, using a slab of clay instead of the dominoes. Next, use a loaf of bread and try pushing against the bread with two wooden blocks. Two students should push against the bread, one from each end.

What observations can you make about the way similar pressures affect different materials? Which type of material would flow more readily under pressure, clay or granite? If you consider only the pressure, would you expect metamorphic changes in clay to occur at a lesser or greater depth than in granite?

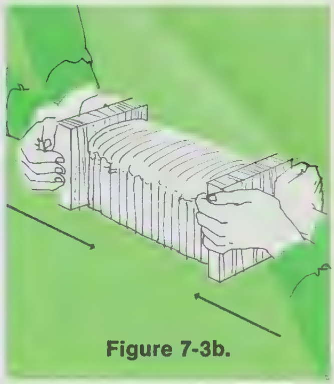
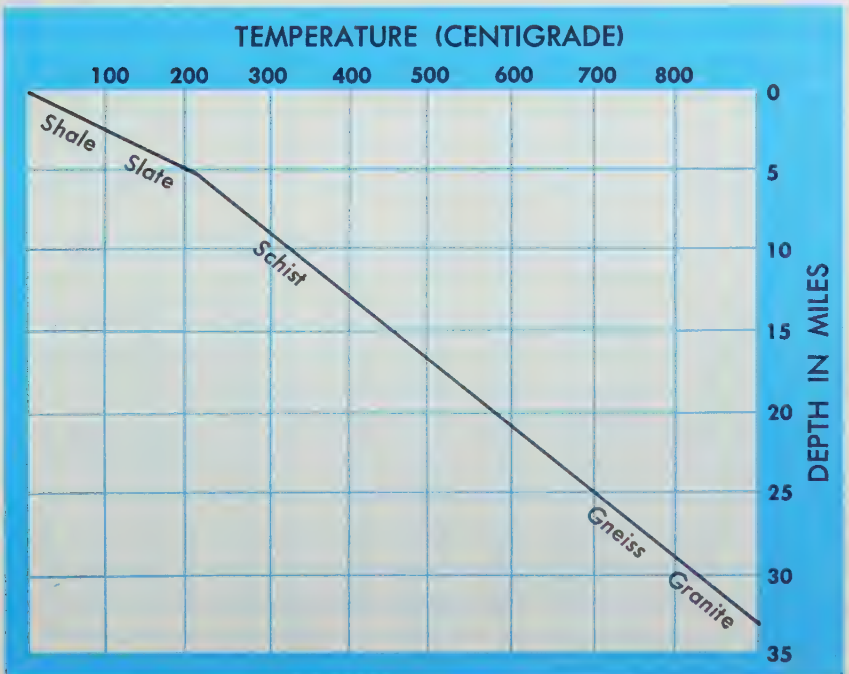


Figure 7-3b.

Thermal (thur′mal) *metamorphism* includes changes due to heat. Although heat is accompanied by pressure, in thermal metamorphism heat determines the kind of metamorphic changes that occur. High temperatures cause a baking effect on the rock, creating a high gloss similar to the glaze on fine china. Enlargement of minerals, or *recrystallization*, is also characteristic of thermal metamorphism. Crystals of fine-grained rocks are enlarged by movements of certain ions from positions of greatest pressure to positions of least pressure. Original minerals are made larger and new minerals are formed, but no new elements are added to the rock and no elements are removed.

Metamorphic processes include thermal, dynamic, and metasomatic changes.

Recrystallization is the enlargement of original mineral crystals and the formation of new mineral crystals during thermal metamorphism.



7-4. As temperature rises with depth, rocks change from sedimentary to metamorphic and eventually to igneous.

EXPERIMENT. Caution: Perform this experiment only under adult supervision. *Determine the effect of heat on minerals under pressure. Put 1 cup of water in a pressure cooker. Place the cooker over heat, and when some steam has escaped, put the pressure gauge on the cooker. Watch the pressure gauge pointer rise to the point marked HIGH. Turn off the heat. What happens to the gauge when the heat is turned off? Explain what occurs within the cooker to make the gauge rise and then fall.*

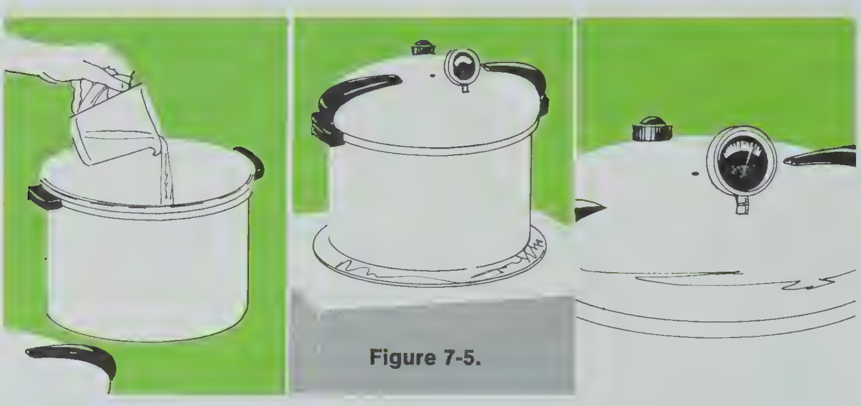


Figure 7-5.

Metasomatism is the growth of new minerals due to an exchange of ions between the original rock and high temperature fluids moving through the rock.

When fluids at high temperatures move through a rock, some ions may be removed from the parent rock. Other ions may be left behind. Many new minerals are formed in metamorphic rocks during this exchange, which is known as *metasomatism* (met e soh′ma tiz um). Some of the new minerals occur only in metamorphic rocks. Some of the new minerals are rare gems, such as rubies and sapphires. Garnets are among the rare minerals typical of metamorphic rocks.

Dynamic (die nam′ik) *metamorphism* includes changes due primarily to pressure. Both temperature and pressure increase with depth, but pressure is the dominant influence except near the core of mountain chains and adjacent to igneous intrusions. Pressure may cause recrystallization and influence the arrangement of mineral grains. Rocks appear to be hard and unyielding at the surface, but under high temperatures and great pressure they become pliable like soft clay. Atoms slide into new positions, and minerals are redistributed to occupy the least possible space. All minerals having one axis longer than the other are realigned like toothpicks in a box. Such changes in mineral arrangement are called *foliation* (foh lee ae′shun).

7:3 Texture

Texture in metamorphic rock refers to the size, shape, and arrangement of grains. Rocks may be foliated, or recrystallized, or have a combination of the two textures. *Foliated textures* are bands or layers. The bands may be as close together as the pages of a book, or they may be several feet apart. Banding often results from the presence of dark-colored mica and light-colored mica. Micas occur in flakes that tend to line up in nearly parallel layers. Amphiboles also tend to be arranged in parallel bands. Rocks containing mica or amphibole often have dark layers alternating with lighter-colored minerals such as feldspar or quartz.

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Figure 7-6. Contorted gneiss.

Recrystallized texture consists of large interlocking crystals. Recrystallization is most common for quartz, calcite, and feldspar. As these minerals increase in size, foliation bands appear farther apart.

Foliation may occur alone or it may occur in combination with recrystallization.

7:4 Composition

Minerals in metamorphic rocks include the same minerals that occur in igneous rocks. But metamorphic rocks also contain certain minerals not found in any other kind of rock.

Metamorphic rocks contain many of the same minerals as igneous rocks.

Shale and sandstone layers contain the same elements as igneous rocks, but the elements are present in different combinations. Feldspars, amphiboles, quartz, and other minerals such as mica are formed from sedimentary rocks during metamorphism. Calcite and quartz recrystallize under pressure regardless of the temperature. Other minerals develop only during thermal metamorphism.

7:5 Metamorphic Rank

Metamorphic intensity, or **rank,** differs from place to place according to the amount of pressure and the temperature. The higher the temperature and pressure, the greater the metamorphic change. Maximum metamorphism occurs close to the center of mountain building, where both temperature and pressure are greatest. The amount of metamorphism gradually decreases with distance from the center of uplift. *Regional metamorphism* is metamorphism that affects a large area. Mountain building usually is accompanied by regional metamorphism.

High rank metamorphism is associated with temperatures of 700°C to 800°C. Low rank metamorphism is associated with temperatures close to 150°C.

Regional metamorphism affects wide areas of mountain building and includes both high and low rank effects.

Figure 7-7. Abrupt contact between schist and granitic intrusion preserved in a weathered boulder.

Contact metamorphism occurs in narrow zones adjacent to igneous intrusions and includes only high rank effects.

Metasomatic changes and thermal metamorphism are at a maximum in the contact metamorphic zone.

Contact metamorphism occurs when intrusions of hot magma change the rock with which they come in contact. Metasomatic changes are characteristic. The hot magma contains liquids and gases that penetrate the adjacent rock and exchange ions with it. Contact metamorphism may be limited to a few inches, or it may include a zone about one mile wide, depending on the size of the igneous intrusion. The contact zone contains rocks of highest metamorphic rank; that is, rocks which represent the most extreme metamorphism. Temperatures are at a maximum (about 800°C or 1472°F) and rocks are changed both chemically and physically. Rare minerals are common in the contact zone. (Figure 7–7.)

7:6 *Classification*

Names are given to foliated rocks according to the width of the layers or bands. As the width between bands increases, recrystallization becomes more important.

Metamorphic rocks are grouped into foliated and nonfoliated rocks. **Foliated rocks** include rocks with banding. Examples of foliated rocks are slates, phyllites, schists, and gneisses.

Slates usually form from shale, and have extremely fine foliation. Layering is difficult to recognize without the aid of a microscope. Occasionally, if a rock is broken across its foliation, layers can be recognized. Minerals, however, are usually too small to be seen. Slate represents the lowest rank of metamorphism, where temperatures are just high enough (150°C or 302°F) for metamorphism to occur. Slates are formed farthest from the mountain core during regional metamorphism and may form at great depths below the earth's surface due to the weight of the overlying rock.

Phyllites are just one step above the slates in metamorphic rank. Layering is similar to that of slates. Mica flakes are present but are barely visible. Mica gives phyllite a shiny surface which contrasts with the dull surface of slate.

Schists are rocks in which recrystallization has occurred, but these changes were not great enough to eliminate foliation. Instead, layers of dark minerals, such as biotite or amphibole, are separated by lighter-colored minerals of feldspar or quartz. Layers are a fraction of an inch to as much as one inch apart. Recrystallized minerals are large enough to be identified. Schists are given a number of descriptive names, depending on the dominant minerals. If quartz is present, the schist is a quartz schist; if one of the micas dominates, it is a mica schist; if garnets are present, the rock is a garnetiferous (gahr net-if′e rus) schist.

Schists form closer to the mountain core than slates or phyllites do. They make up vast areas of regionally metamorphosed rocks, representing intermediate temperatures of 200°C or 300°C (392°F or 572°F) up to relatively high temperatures of about 700°C (1292°F). Schists are the most common metamorphic rocks and may come from a variety of parent materials such as shale, impure limestone, or even basalts.

Paul W. Nesbit

Figure 7-8. Rocks from the mountain core often contain layers of schist intruded by granitic rock.

Gneiss (nies) is a metamorphic rock that looks like granite. However, gneiss has rough layering of the dark constituents. Either biotite or amphibole may be present in widely separated layers which are inches or even feet apart. Gneiss represents the maximum rank of metamorphism, except for the contact zone. Gneiss occurs in association with the mountain core, and may grade gradually into true igneous granite-type rocks. Gneisses are commonly confused with schists.

Nonfoliated rocks include rocks without banding. Two examples of nonfoliated rocks are marble and quartzite.

Nonfoliated rocks exhibit recrystallization without banding.

Marble is the recrystallized rock which comes from pure limestone. Some limestone and marble are so similar that it is sometimes difficult to tell them apart. However, marble is harder than limestone and the crystals in marble are larger. Marble may be pure white or, when colored by impurities, it may be black, red, yellow, or green.

Quartzite is the recrystallized metamorphic rock derived from quartz sandstone. It is a hard rock with a wide range of colors due to the various colors of iron stain or other impurities. Single-mineral rocks, such as sandstone and limestone, recrystallize without foliation because no contrasting minerals are present to form bands.

Serpentine, also called serpentine marble, is a green crystalline metamorphic rock. Serpentine forms during the alteration of a basalt. Serpentine may be associated with marble. If cut into slabs and polished, it is used as a decorative rock called green marble.

ACTIVITY. Examine several specimens of metamorphic rock. Use your collection of metamorphic rocks and some from the room collection. Classify the rocks into foliated and nonfoliated groups. Assign them names according to the metamorphic rock chart. (Table 7–1.)

Indicate that the rocks are metamorphic by labeling them M *with India ink in a small area of white paint. Place a number after the* M *and write both the number and the name in your notebook. Indicate the possible source rock for each of the specimens. What are the characteristics by which you recognize each rock?*

Put a drop of 15 percent hydrochloric acid (HCl) on each rock, wait for a reaction, and then quickly wipe it off. Record which of the rocks starts bubbling when HCl is dropped on it. Test each rock for hardness. (Table 4–3.) Which rocks cannot be scratched with a knife? Examine the fine-grained rocks with a magnifying glass to see whether you can identify the minerals. What mineral is present in the dark layer of the schist?

Write a paragraph in your notebook telling what similarities and differences you observe between metamorphic rock and igneous rock. Are any of the metamorphic rocks similar to sedimentary rocks?

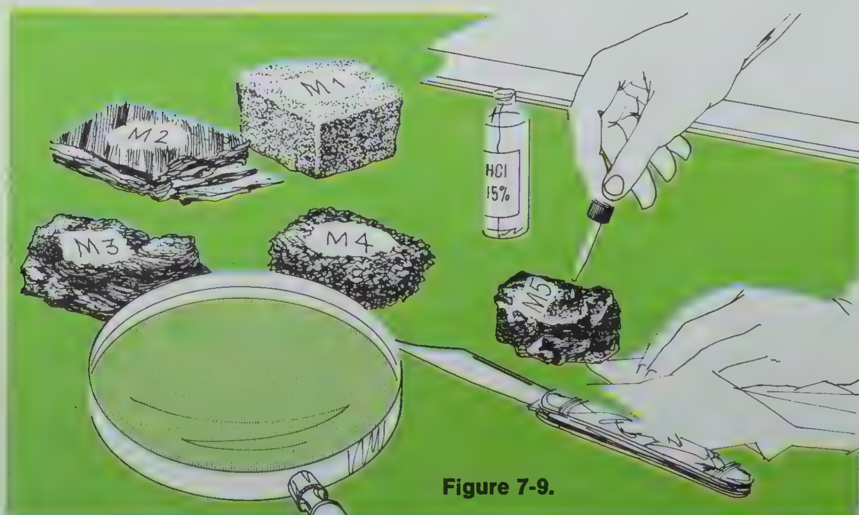

Figure 7-9.

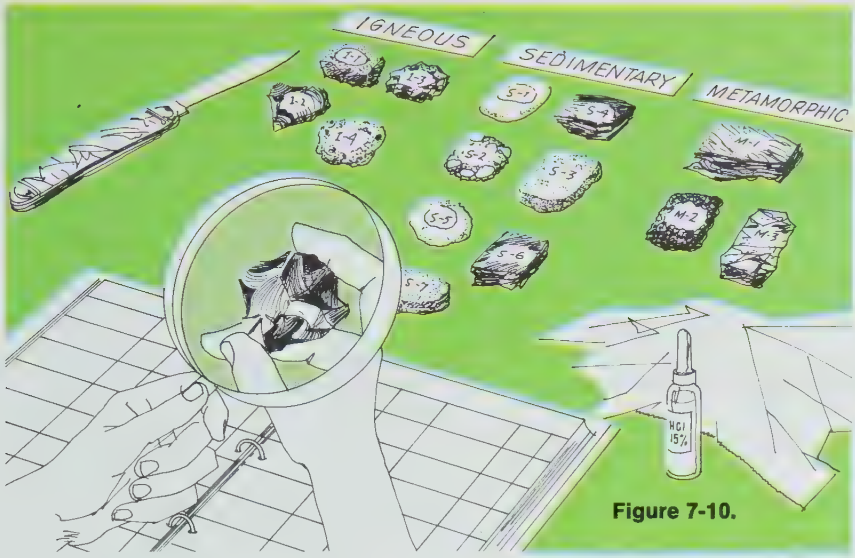

Figure 7-10.

ACTIVITY. Use a set of identified and labeled rocks. The rocks should include chert, chalcedony, obsidian, granite, conglomerate, chalk, pumice, coal, basalt, slate, limestone, sandstone, gneiss, marble, and shale. Carefully break off a piece of each of the rocks to expose a fresh, unweathered surface. Test the surface with a steel knife for hardness. Put a drop of 15 percent hydrochloric acid on each sample. Examine the rock surface with a magnifying glass. Record your answers to the following questions about the rock samples:

1. *Which rocks give off bubbles when tested with hydrochloric acid?*
2. *Which rocks have crystals?*
3. *Which rocks feel gritty to the fingers?*
4. *Which rocks have many openings?*
5. *Which rocks have layers?*
6. *Which rocks have a distinct odor?*
7. *Which rocks look like glass?*
8. *Which rocks are made of pebbles?*
9. *Which rocks make a mark on your hand or paper?*
10. *Which rocks may be used in arrowheads?*
11. *Which rocks can you use for writing?*

Classify the rocks into igneous, metamorphic, and sedimentary groups. List each group and its members in your notebook. Compare your unmarked samples with the set of identified and labeled rocks. Examine your unmarked rocks and classify them into the three types. Put a small square of white, waterproof paint on your samples. Use India ink to number each rock to correspond with the number on the known sample. In your notebook, list the number and the name of each rock sample.

Table 7-1. *Metamorphic Rock*

	Texture		*Name*	*Rank*	*Origin*
	Arrangement of Grains	Size of Grains			
FOLIATED	Layers almost invisible	Microscopic	Slate	Lowest	Shale and siltstone
FOLIATED	Layers almost invisible	Microscopic (except for mica flakes)	Phyllite	Low	Shale and siltstone
FOLIATED	Layers visible to ½ in. apart	Recognizable	Schists	Intermediate to high	Extrusive igneous rock; shale, siltstone, impure sandstone, impure limestone
FOLIATED	Layers ½ in. to several feet apart	Easily recognizable	Gneiss	Highest	Intrusive igneous rock; shale, siltstone
NONFOLIATED	No layers	Calcite minerals easily recognizable	Marble	All ranks	Pure limestone
NONFOLIATED	No layers	Quartz minerals easily recognizable	Quartzite	All ranks	Pure sandstone
NONFOLIATED	No layers	Serpentine minerals easily recognizable; occasionally calcite is present	Serpentine	All ranks	Basalt, peridotite

Figure 7-11. Slate.

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Figure 7-12. Schist.

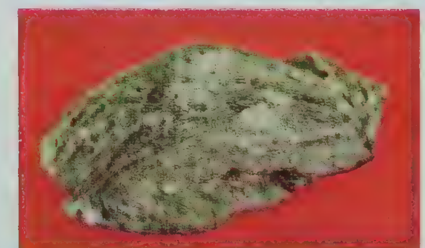

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Figure 7-13. Gneiss.

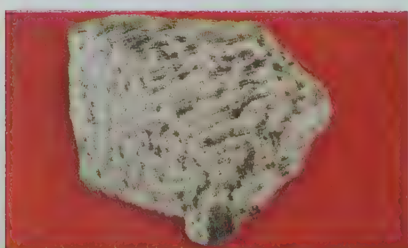

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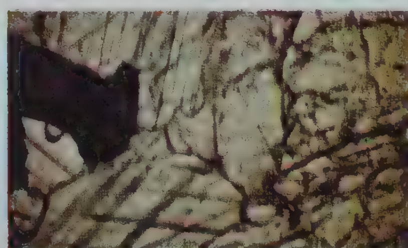
Figure 7-14. Marble (spinel-chrondrodite).



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MAIN IDEAS

1. Metamorphic rocks, which are less abundant than either igneous or sedimentary rocks, are formed at temperatures as high as 800°C and under great pressure while the rocks remain in a solid state.

2. The heat which causes metamorphism is produced by radioactive decay, friction during mountain building, pressure, or intrusions of magma.

3. Pressure is caused by a heavy burden of overlying rocks, crustal movement or uplift, or intruding magma.

4. Thermal metamorphism (metamorphism by heat) may cause rocks to recrystallize or to form new minerals by rearrangement of ions.

5. Igneous intrusions of liquid rock may cause the exchange of ions along points of contact with other rocks (metasomatism).

6. Dynamic metamorphism (metamorphism by pressure) plus heat causes foliation or rearrangement of minerals in layers.

7. Regional metamorphism, which may cover large areas, occurs where mountain building or crustal activity is taking place.

8. Contact metamorphism, the result of igneous intrusions, is of the highest rank.

9. The minerals in metamorphic rocks are the same ones found in igneous rocks with a few rare additions.

10. Metamorphic rocks showing various degrees of metamorphism and foliation are: *slates*, lowest degree of metamorphism and fine foliation; *phyllites*, much like slates only with visible mica flakes; *schists*, with both foliation and recrystallization, moderate metamorphism, often confused with gneisses; *gneiss*, some foliation, and complete recrystallization, high rank metamorphism.

11. Metamorphic rocks which do not show foliation are classified as recrystallized. Nonfoliated rocks include: marble, from limestone; quartzite, from sandstone; serpentine, possibly from basalt.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

contact metamorphism	radioactive elements
dynamic metamorphism	rank
foliation	recrystallization
gneiss	regional metamorphism
metasomatism	schists
migmatites	serpentine
phyllites	slates
quartzite	thermal metamorphism

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. The banding of metamorphic rocks is called foliation.
2. The hardest rocks may become pliable under pressure and high temperatures.
3. Metamorphic rocks closest to a mountain core are slate.
4. Slates are foliated metamorphic rocks.
5. During recrystallization, combinations of atoms adopt new geometric shapes that require less space than the former shape.
6. Gems, such as rubies, are produced during metasomatism.
7. Metamorphic changes are common at the surface of the earth.
8. Low rank metamorphism occurs at temperatures of approximately 800°C.
9. High rank metamorphism is due to pressure alone.
10. Metamorphism does not involve melting.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. A metamorphic rock which closely resembles granite is (*slate, marble, gneiss*).

2. Metamorphism in which pressure is the dominant controlling factor is called (*dynamic, thermal, contact*) metamorphism.
3. The three most common minerals formed during recrystallization are (*mica, calcite, feldspar, amphibole, rubies, quartz, garnets*).
4. Slate is a metamorphic rock derived from (*basalt, sandstone, shale*).
5. The metamorphic rock that forms from limestone is (*gneiss, schist, marble*).
6. Metamorphic rock which contains alternating layers of metamorphic and igneous rock is called a (*geode, gneiss, migmatite*).
7. Phyllites can be differentiated from slates by the presence of (*mica flakes, quartz crystals, wide banding*).
8. Thermal metamorphism includes metamorphic changes due mainly to (*heat, pressure, ion exchange*).
9. A zone of contact metamorphism is associated with (*low rank metamorphism, dynamic metamorphism, metasomatism*).
10. The foliated rock which would be found closest to a mountain core is (*slate, gneiss, schist*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The agents of metamorphism are ___?___ and ___?___.
2. Regional metamorphism often takes place during periods of ___?___.
3. Two precious minerals associated with metamorphic rocks are ___?___ and ___?___.
4. Textures of metamorphic rocks are either ___?___ or ___?___.
5. Most minerals in metamorphic rocks are the same as the rock-forming minerals found in ___?___ rocks.
6. The enlargement of old minerals and the forming of new ones during metamorphism is called ___?___.
7. If new ions are added to the rock, or ions are removed from a rock during metamorphism, the process is called ___?___.

8. Marble and quartzite are formed by ___?___.
9. Igneous intrusions may be associated with both pressure and high temperatures. In the vicinity of the intrusion, the effects of ___?___ are most evident.
10. The amount of metamorphism, or degree of change, is called ___?___.

D. How and Why

1. By what simple test can you distinguish between marble and quartzite? Can you use the same test to distinguish between marble and limestone?
2. Why should minerals in both metamorphic and igneous rocks be the same?
3. What is the most important source of heat for metamorphic processes? Is there any relationship between this heat source and pressure?
4. You have not yet studied mountain building, but you have been given some clues in this chapter to the relationship between mountain building and metamorphism. What information has been developed up to this point to indicate that sedimentary rocks may be buried and then uplifted?
5. Sometimes gneiss layering has several feet between bands. If you had a specimen taken from the section between bands, how would you classify the rock?
6. Schists have the greatest variety of minerals of any of the metamorphic rocks. Can you account for the variety? Contrast the origin of a schist with the origin of marble or quartzite.

INVESTIGATIONS

1. Draw a diagram illustrating the cycle of changes which rocks undergo to become sedimentary, metamorphic, and igneous rock. Remember that the cycle does not necessarily follow the same pattern every time .
2. Prepare a report on the quarrying of marble, limestone, slate, or granite.
3. Make a classification chart for metamorphic rocks on the order of those given for igneous and sedimentary rocks. Be sure to use "foliated" and "nonfoliated" as main divisions.

Indicate the parent rock for each metamorphic rock type and show what minerals are present. Use the igneous chart (Table 5–3) and the sedimentary chart (Table 6–1) to identify the minerals.

INTERESTING READING

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Hyler, Nelson, *The How and Why Wonder Book of Rocks and Minerals.* Columbus, Ohio: Charles E. Merrill Books, Inc., 1960.

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8 Products of the Lithosphere

During the Stone Age, most of the weapons and tools which were available were made of stone. Since those days, innumerable tools and weapons have been designed. But, like the stone objects, all of them have come from minerals or rocks found in the earth's crust.

8:1 *Utilization*

During the Stone Age, weapons and tools were made of flint, chert, or any ordinary stone found on the earth's surface.

Early man did not attempt to classify the kind of rock he picked up. He was more concerned with its usefulness. By accident or by trial and error, man found that he could chip certain rocks to make a sharp edge that was useful for cutting and scraping. *Chert*, also called *flint*, could be made with the best edge and became the first eagerly sought industrial mineral. Indians traveled to Ohio and Texas to find the right kind of chert for their arrowheads.

Later, man discovered that rubbing flint against a fine-grained sandstone would produce an even sharper edge. Thus, he discovered another industrial mineral, the grindstone. *Fine-grained sandstone* is still in demand as a grinding tool.

During the Stone Age, man discovered that he could store and preserve food in a container. He experimented with clay and learned to make pottery. Thus, he added *clay* to the economic products of the time.

The Bronze Age began when man discovered how to make weapons and tools of copper or combinations of copper and tin.

The Bronze Age began when man discovered *copper* and *tin*. Bronze is a mixture of tin and copper which is harder than copper alone. However, in many areas that had copper, there was no tin. In these regions, man had to use copper alone for tools, weapons, and ornaments.

Next, man discovered how to use *iron*. Because iron is not naturally soft and malleable like copper, iron must be melted

and treated while hot to make it usable. Minerals which contain iron are plentiful and widely distributed. Man learned to extract iron from its ores hundreds of years before the birth of Christ. Probably, primitive man discovered metallic iron when he built great fires against the banks of red rock containing hematite. (Table 4–5.) The heat and gases of the fire may have released iron from its combination with oxygen in hematite (Fe_2O_3), and the metal remained in the ashes of the fire. Man learned that he could shape the newly discovered metal while it was still white-hot. By repeated heating and pounding, impurities were released, and its particles were bound tightly together. Man had discovered a hard, strong material in the charcoal ashes. Thus, the Iron Age began.

The Iron Age began when primitive man learned that iron could be shaped while it was white hot.

At first, iron was considered so precious that its use was limited to rings and ornaments. However, man soon found many other ways to utilize this new material. For example, he made chariot wheels of iron, and he used iron in the construction of Solomon's temple. Steel is one of today's products which is made of iron. It is nearly impossible to imagine life without the steel industry. Iron is still the major industrial and economic metal in the world, although the present time is often called the Atomic Age. During World War II, man first learned to use the energy in the nucleus of the metal uranium. Today, uranium is used as a source of energy, mainly in the production of electricity.

Modern civilization depends on a wide variety of metallic and nonmetallic minerals.

Figure 8-1. Rocks and minerals have both functional and aesthetic uses: a. carved bowls (top row, l to r) lapis, amazonite, agate (bottom row, l to r) rhodonite, malachite; b. hand ax of igneous rock.

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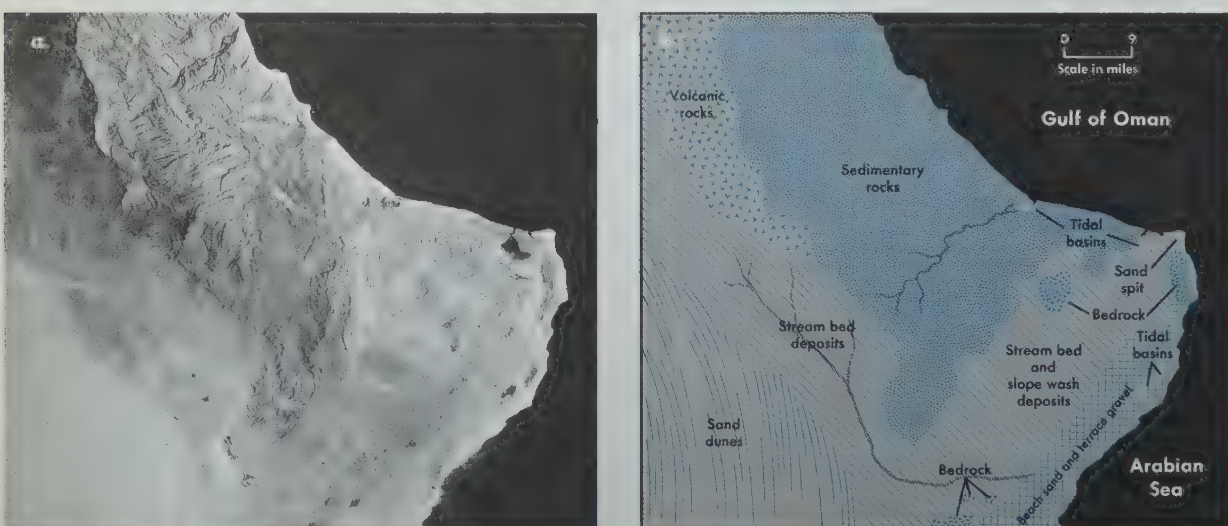
8:2 Ores

Chert, clay, copper, and iron are products of the lithosphere that were readily available to early man. These products are still among the most abundant and useful materials of the lithosphere. However, in the thousands of years since the discovery of iron, many other minerals have become important and useful. Our world has changed greatly from the days of the Stone Age, largely because man has learned to use a variety of metals.

Ores are metallic or nonmetallic minerals which can be mined at a profit.

Minerals or groups of minerals that can be mined at a profit are called **ores.** Originally the term ore was limited to minerals containing metals. Today, the term includes both metallic and nonmetallic minerals that have economic use. Only those minerals that contain a sufficiently large amount of the useful product are classed as ores. In general, mining and treating of ores yields a relatively small amount of the valuable product compared to the amount of valueless rock that must be handled. For example, one ton of ore may yield only four pounds of copper. Copper ores also may contain other metals, such as gold. The Utah Copper Mine at Bingham, Utah, recovers about 35 cents worth of gold from one ton of copper ore. If the rock contains less than 35 cents worth of gold per ton, it is too low grade to be mined for gold. Low grade deposits may become ores if the price of the valuable metal increases enough, or if more efficient mining and treating methods make it profitable to work low grade deposits.

Figure 8-2. Photos taken from spacecraft aid the geologist in his mapping of terrain and furnish clues to favorable areas for further exploration: a. Arabian Peninsula from distance of 120 miles, b. companion geologic map showing surface rocks in the same area as the photo.



NASA

Valuable ores are almost always mixed with lower grade mineral deposits and waste rock. During mining operations, these useless minerals and rock are brought to the surface along with the ore. The waste rock, or *gangue* (gang), is removed by crushing and treating. The concentrated ore then is smelted and refined to eliminate all substances except the valuable, wanted product. The smelting process consists mainly of chemical treatment to remove sulfur, oxygen, and other impurities.

Gangue is the low-grade mineral and waste rock removed with an ore during mining.

8:3 Metals

Metals are heavy elements that are *malleable* (mal′ee a bl); that is, they can be shaped by pounding without a loss in strength. Metals differ from one another in many of their properties, but all metals are malleable to some degree. Metals also are *conductors of electricity*, and some metals are especially useful because of this property.

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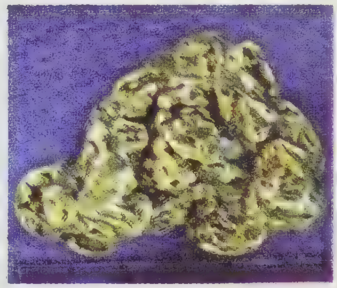


Figure 8-3. Large gold nugget 1½ inches long.

In most ores, metallic elements occur in combination with oxygen, sulfur, or carbon and oxygen. Copper, gold, tin, and occasionally silver occur as *native metals*; that is, the element is in an uncombined form. Both native metals and metals which are combined with sulfur tend to have metallic luster. Metals in other combinations may have nonmetallic luster.

Most metallic ores occur in regions of igneous rock. Mountainous regions, and areas where mountains have been present but now are worn down, are the most favorable locations for prospecting for metallic ores. Metallic elements are present in the gases and liquids that rise to the top of a magma. You can picture the cooking of a thick pudding as magma. Steam rises and bursts the surface in big bubbles as it escapes. Like the steam in a pudding, fluids rise to the top of the magma and escape into the surrounding rock openings. The fluids cool as they invade the country rock openings, and the contained minerals crystallize from the escaping fluids. Thus, ores are common near the top of an igneous intrusion such as a batholith. Ores also may be present as *veins*, or fillings of former openings. (Figure 8–5.) Often, ore bodies are so numerous that they resemble the branching blood veins of the human body. However, some ore veins are too narrow or too short to be worked profitably. In some veins, metals occur in combination with other elements that cannot be removed profitably. All veins contain

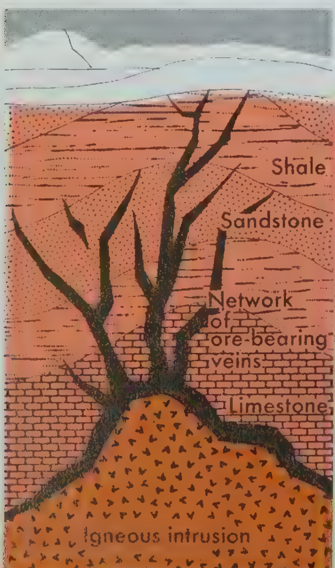
Metallic ore bodies are most common in regions of igneous intrusions.

Figure 8-4. The low density rocks that occur with gold placers may be floated away, leaving the heavier gold on the bottom of the sluice box.

gangue. The most common gangue minerals are quartz and calcite.

Once they are deposited, some metallic deposits remain unchanged. Other deposits are near enough to the surface to be affected by weathering. Copper ores often are concentrated into richer deposits by percolating waters. Copper sulfides are insoluble, but when they are changed to copper sulfates by chemical reactions in the zone of weathering, they may be dissolved. The copper sulfates are carried downward in solution, and, at some depth, undergo other chemical reactions which change them into copper sulfides once more. The sulfides then precipitate from solution and are added to the copper sulfides which have not undergone weathering. In this way, the amount of copper in the vein is increased, and the deposit becomes more concentrated.

Figure 8-5. Gases and liquids from the magma follow cracks in the country rock where they are consolidated to form veins. Veins often are ore-bearing.



Like copper ores, the great iron deposits of North America also have been concentrated by weathering. But unlike copper deposits, the unwanted substances were removed, leaving the iron behind. Iron ores were exposed at the surface of the earth for millions of years. Rocks containing the iron ores were weathered. Clay and silica were carried away, and the iron deposits were enriched as the worthless material was removed.

Gold is another metal which is concentrated into profitable deposits by weathering and erosion. Discovery in 1848 of sedimentary gold deposits, called *placers* (plas′erz), influenced the

great westward migration in the United States in 1849. Originally, the gold occurred in veins high in the California mountains. Weathering caused the rocks containing the veins to crumble. Streams flowing down the mountainsides carried gold grains and nuggets, along with rock fragments, to the foot of the mountains. When the streams reached the foot of the mountains, their velocity decreased. As streams lost their velocity, they lost their ability to carry much of the material picked up in the mountains. Gold was deposited along with sand and gravel in the stream beds. Miners came and panned the gravels to separate them from the gold. Many prospectors followed streams up to the mountain tops to find the original veins from which the gold had been weathered. The great Mother Lode vein in California was discovered in this way. Many veins, however, had been completely eroded away, and all of the gold had been carried down to the foot of the mountains.

Placer deposits are found along stream beds where minerals of high density have been deposited with sand and gravel as the stream's velocity decreases.

Tin, iron, platinum, and even diamonds have been found in riverbeds and along shores as placer deposits. Metals that are heavy tend to be left in riverbeds or along shores where water has carried away the finer, less dense sediments.

Lead, zinc, copper, and many other metallic ores do not occur as placer deposits. These ores occur in veins, or as masses within country rock, and they must be mined by means of shafts driven into the rock or from great open pits.

The Anaconda Company

Figure 8-6. Ores that occur near the surface are mined in open pits from which the overlying soil has been removed. Great quantities of rock are carried away as the mine is deepened.

8:4 Nonmetals

Nonmetals are products of the lithosphere that do not contain metal. They include many products that have no common characteristics.

Nonmetals are also called industrial minerals. **Nonmetals** include such a wide variety of products from the lithosphere that, unlike metals, they have few common characteristics. Industrial minerals include building stones, clay, limestone, fertilizers, and the source rock for many chemical products. Many industrial minerals are widely distributed and relatively abundant. Because so many of the nonmetals are used every day, they seldom are regarded as valuable economic products. Sand is used in making glass and cement. Lime is used in cement, as fertilizer, and in hundreds of other common products. Gravel is used for roads. Sandstone, limestone, granite, marble, and serpentine are all useful as building materials. Table salt comes from halite. Graphite is a component of pencil lead. Potash, nitrates, and phosphates are used in commercial fertilizers. Sulfur is used to manufacture sulfuric acid. Fluorite yields fluorine. Sodium compounds play a part in the preparing, processing, or manufacturing of many of the things you eat, drink, or touch. The list of industrial products from the crust of the earth is almost endless.

Figure 8-7. Salt is an industrial mineral which may be mined or dissolved and brought to the surface as a brine from which salt is then precipitated.

Caterpillar Tractor Company

Texas Gulf Sulphur Company

Figure 8-8. Much of the sulfur in the United States comes from salt domes of the Gulf Coast region. The sulfur occurs with anhydrite and calcite forming a hard layer called caprock above the salt.

Sulfur alone has thousands of uses, and the number constantly increases. Sulfur is used in dyes, fertilizers, pharmaceuticals, rubber, and in iron and steel. The amount of sulfur used by a nation is said to indicate that nation's industrial activity. The United States leads all other nations in the consumption of sulfur.

Sulfur is a source for many products and an index to the industrial activity of a nation.

Gems are products of the lithosphere that are used for decoration. Gems must have beauty, durability, and rarity to be regarded as desirable. Of the more than 2,000 known minerals, only about 80 have the attributes required of gems. From the beginning of recorded history, and probably even before, certain crystalline minerals have been highly prized. The most desirable gems are called *precious stones;* gems that are less rare and less costly are called *semiprecious stones.*

Gems are valuable because of beauty, durability, and rarity.

Precious stones in ancient Egypt, India, and China attracted trade from Europe. Probably the desire for gems, as well as spices, was responsible for the opening of early trade routes between China, India, and Europe. The Incas of the New World had stores of emeralds, diamonds, amethysts, and other precious and semiprecious stones in their temples. Gems never seem to lose their value and desirability. Men have fought and died trying to obtain them. Yet gems are valuable only because of their appeal to a sense of beauty. Greatest values are attached to gems that are rare, free from defects, and perfectly cut. Diamonds, emeralds, rubies, and sapphires continue to be the most highly prized gems.

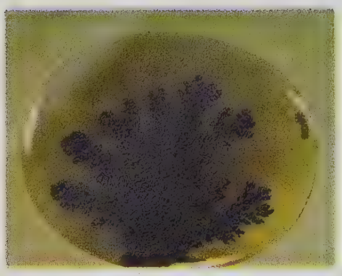


Figure 8-9. Cabochon of quartz with arborescent moss agate pattern.

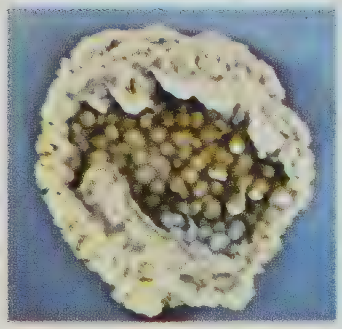
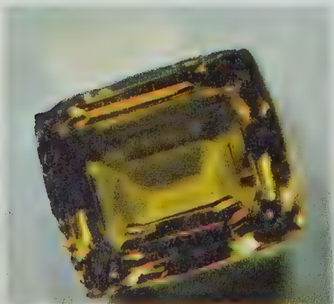


Figure 8-10. Half of large geode of chalcedony.



Photos From Ward's National Science Establishment, Inc.

Figure 8-11. A 93 carat cut yellow sapphire gem.

Semiprecious stones, although not as valuable as precious gems, are very popular. Many varieties of crystalline quartz—including citrine (yellow), amethyst (purple), rose quartz (pink), and colorless quartz—are cut, polished, and mounted to make jewelry. *Agate*, the banded quartz, and *chalcedony* (kal sed′en ee), the colored microcrystalline variety of quartz, are in great demand. The golden variety of *topaz*, a crystalline mineral, is highly prized. *Opals*, especially those known as fire opals, rank close to the precious gems. In the past, opals were believed to bring bad luck. Today, this superstition has largely disappeared and opals are in great demand because of their beauty .

Most gems are silicates. This group includes emerald, tourmaline, topaz, and quartz. Oxides, the next largest group of gems, includes ruby and sapphire. Diamond is made of the element carbon.

Amorphous, or cryptocrystalline gem materials, are commonly cut and polished into a smooth, convex form called *cabochons* (kab′a shahns). First the gem is sawed into a small slab. Then it is ground into the desired shape, sanded, and finally polished. Gem materials of least value are often tumbled with a polishing material in a container. Irregular shapes, called *baroques* (ba rohks′), are formed by tumbling. Transparent, crystalline gems such as diamonds are usually *faceted* (fas′et ed), or cut into smooth, plane surfaces. Gems should have a hardness of 7 or above in order to be cut. Facet cutting is an art in which gems are cut into many small faces. Some gems have as many as 104 faces, cut and polished to reflect and refract light and thus give the crystal a brilliant appearance.

8:5 *Mineral Fuels*

Metals and nonmetals may be found in any kind of rock. Mineral fuels are almost always found in sedimentary rock. Mineral fuels are products of organic decay in the absence of oxygen. The usual environment for the forming of fuels is a swamp or deep hole on the sea bottom, away from sunlight and scavengers. *Scavengers* (skav′in jers) are animals that live on dead matter and, thus, destroy it. Wave action also prevents the preservation of organic matter by breaking it up and allowing it to combine with oxygen. Organic matter contains the elements carbon, hydrogen, oxygen, and nitrogen. If decay occurs

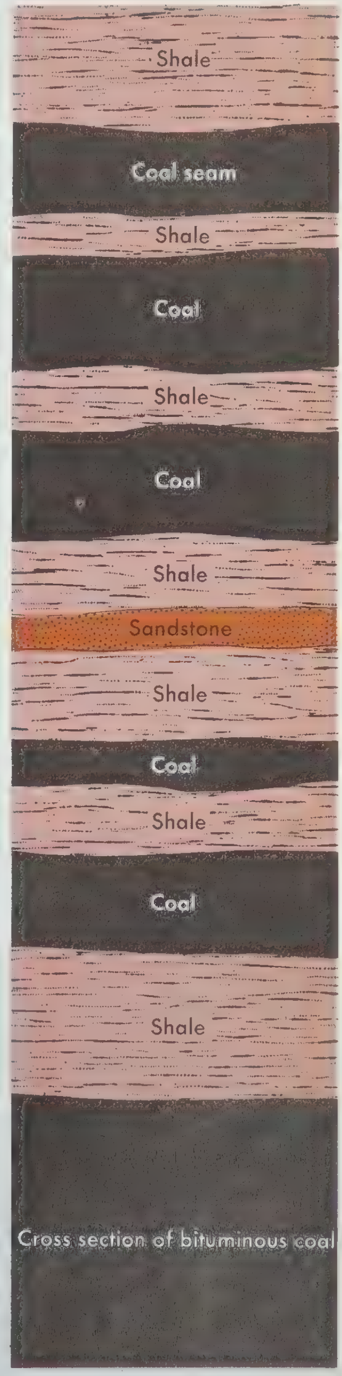
where oxygen is present, the organic matter is oxidized; that is, it combines with oxygen. If decay occurs where oxygen is absent, both nitrogen and oxygen are lost and only carbon and hydrogen remain. These combinations of carbon and hydrogen reunite with oxygen when they are used as fuels. During this process, called *burning*, light and heat are given off. Consequently, *hydrocarbons* (hie dra kahr′bons) are important sources of heat energy.

Examples of mineral fuels include coal, petroleum or oil, and natural gas. All these substances are hydrocarbons. *Coal* is a sedimentary rock made from the decayed remains of vegetation. Tree roots, twigs, leaves, and stems are subjected to pressure by overlying sediments when they are buried in a swamp environment. Water is squeezed out by the weight of sediments above the vegetation. *Peat* is the first form in coal formation. Twigs and leaves that can be seen in peat indicate that little change beyond compaction has occurred. *Lignite*, also called brown coal, is low grade coal which has lost most of its moisture, and has become a compact mass in which only occasional pieces of vegetation can be seen. Lignite requires a longer time and deeper burial for its formation than peat. *Bituminous coal*, or soft coal, represents even longer burial and more pressure from overlying sediments. Bituminous coal has lost much of its original oxygen and nitrogen, as well as its original moisture. *Anthracite*, also called hard coal, occurs only in the regions of mountain building or near igneous intrusions. Anthracite is a metamorphic rock rather than a sedimentary rock. Much greater heat and pressure are required for the transformation into anthracite than for the forming of bituminous coal.

Petroleum, or oil, is a liquid fuel. Petroleum comes from the decay of marine organisms, and perhaps from *diatoms* (die′a tahms), abundant one-celled protists that float on the surface of the sea. Oil usually forms in muds, in parts of the sea where water circulation is limited and oxygen is absent, or in lagoons cut off from the wave action of the main body of the ocean.

As muds are covered with younger sediments, organic matter and water are squeezed out. The shales that form are neither porous nor permeable. Fluids cannot remain in the compact shales that are formed and are forced into adjacent beds of porous and permeable rock, such as sandstone or limestone. Oil collects between the grains of sandstone, or along the bedding planes of either sandstone or limestone. When water

Figure 8-12. Swamp conditions alternating with marine conditions give rise to coal layers between shale formations.



Oil is found in permeable rocks, usually at the highest position of such beds or where permeable rocks grade into impermeable materials.

moves through the rocks, it carries oil along with it. Because oil is less dense than water, it rises to the highest position in the permeable bed. Rock bodies in which oil collects are called *oil pools*. However, the term oil pool does not imply that oil is present in a large opening in the rocks. Actually, oil is present in large quantities, but it is distributed in the small openings between grains. Petroleum occurrence is limited because some change in rock position, or in rock permeability, is necessary for large quantities to accumulate. If the rocks are bent upward into a large arch, or *anticline*, oil tends to rise to the top of the arch and remain there. (Figure 8–13.) Where permeable rock grades into impermeable rock, the oil accumulates at the boundary between them. Oil is often trapped where sandstones grade into shales. (Figure 8–14.)

Oil may be changed to gas by heat and pressure, or the change may occur over long periods of time.

Natural gas, another form of hydrocarbon, is similar to oil. Some combinations of hydrogen and carbon tend to be gases instead of liquids. The gaseous hydrocarbons usually take longer to form than the liquid hydrocarbons. Great heat tends to turn the liquids into gases. Gas is less dense than oil, and where both oil and gas are present, the gas rises above the oil and accumulates at the top of the oil pool.

A few shales, known as *oil shales*, have retained organic matter. The organic matter can be extracted as oil, but at present the process is too expensive for general use. As oil resources diminish, oil shales may be utilized as a source of petroleum.

Figure 8-13. Gas, oil, and water are arranged in a reservoir rock according to their respective densities. In structural traps, the oil and gas occupy the highest position within the permeable rock.

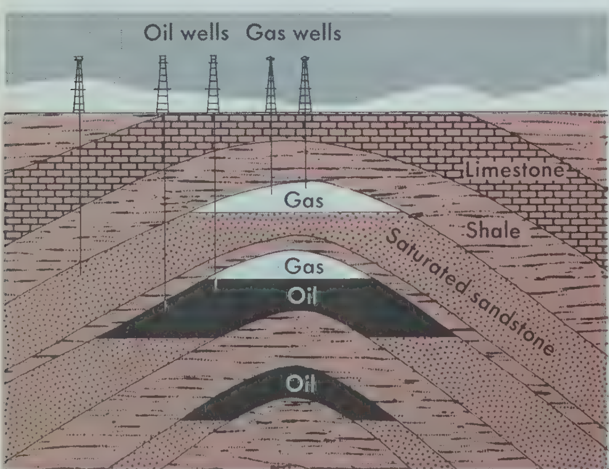
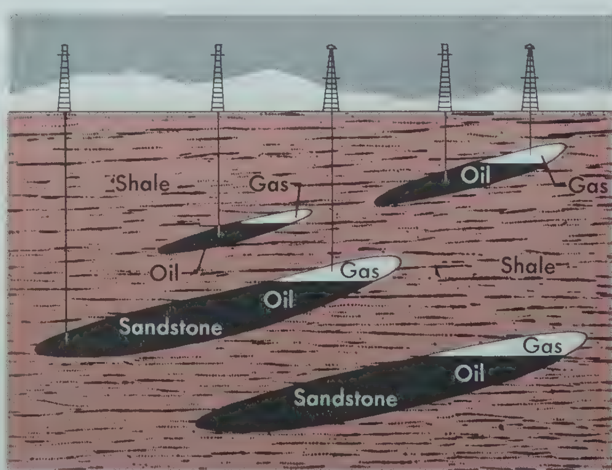


Figure 8-14. In stratigraphic traps, oil and gas are held within lenses of permeable rock (thick in the middle and thin at the edges) surrounded by impermeable layers.



ACTIVITY. Prepare a report on material you have been collecting during the school term. The report may cover a variety of products of economic importance. You may approach the subject from the standpoint of its history, its mining and preparation for industrial use, or its geographic distribution. Samples of the products should be mounted for display. If you treat the topic from the standpoint of preparation, the sequence of mining and treatment makes an excellent display. If you treat the topic from the geographic standpoint, prepare a map of the area and its products.

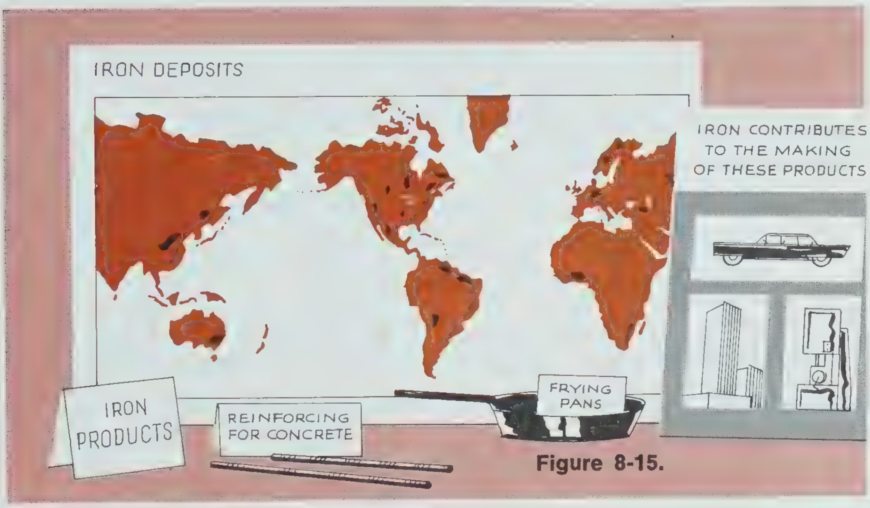


Figure 8-15.

MAIN IDEAS

1. Man's use of products of the lithosphere progressed from the Stone Age, through the Bronze Age, into the Iron Age and the present.
2. Valuable products of the lithosphere (ores) include metals and nonmetals.
3. Metallic ores are associated with igneous intrusions in the form of veins.
4. Percolating water may concentrate some metallic ores in veins; streams may distribute ores in placer deposits in their beds, or expose them in place by wearing away the covering sediments.
5. Gems are the most precious of the nonmetallic ores.
6. Nonmetals include building materials, fertilizers, chemical source materials, and many other earth products.

7. Most mineral fuels are associated with sedimentary rock formations.
8. Most coal, formed of decayed plants, is found in sedimentary rock layers.
9. Anthracite coal is found where mountain building has metamorphosed the plant remains.
10. Petroleum and natural gas, formed from decayed marine animals and plants, are found in sandstone and/or limestone deposits.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

cabochons	nonmetals
diatoms	ores
gangue	peat
gems	petroleum
hydrocarbons	placers
industrial minerals	precious stones
lignite	scavengers
metals	semiprecious stones
native metals	veins

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. The Stone Age immediately preceded the Iron Age.
2. Stone Age men discovered the principle of the grindstone.
3. Bronze is a good substance for weapons because it is harder than iron.
4. Minerals containing iron are widely distributed.
5. Minerals containing metals can be mined at a profit.
6. Profitable construction materials come from sedimentary rocks.
7. Natural gas is found on top of petroleum in an oil field.

8. A large amount of ore yields a relatively small percentage of valuable metal.
9. Native metals occur as elements, not chemical compounds.
10. The most desirable gems are called semiprecious stones.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Stone Age weapons were made of (*calcite, chert, copper*).
2. Metals are closely associated with a(n) (*igneous, sedimentary, metamorphic*) rock origin.
3. Placer deposits may include (*gold, halite, sulfur*).
4. Nonmetallic ores that occur as evaporites include (*copper, rock salt, chert*).
5. Most of the mineral fuels are found associated with (*igneous, sedimentary, metamorphic*) rocks.
6. Precious gems are minerals which occur most often in (*sedimentary and igneous, sedimentary and metamorphic, metamorphic and igneous*) rocks.
7. Clay, chert, and fine-grained sandstones were the first industrial minerals which were discovered during the (*Bronze Age, Stone Age, Iron Age*).
8. The two most common gangue minerals are (*tin and copper, hematite and limonite, quartz and calcite*).
9. Petroleum forms during the decay of (*marine organisms, scavengers, swamp vegetation*).
10. (*Mineral fuels, Industrial minerals, Native metals*) may be classified as hydrocarbons.

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Stone Age men used __?__ to sharpen their tools and weapons.
2. Bronze is an alloy of __?__ and __?__.
3. The term ore includes both __?__ and __?__.
4. Waste minerals removed along with ore during mining are called __?__.

5. The nonmetallic source for bricks is __?__, for cement is __?__ and __?__, for glass is __?__, for salt is __?__, and for pencil lead is __?__.
6. Anthracite coal is a(n) __?__ rock.
7. A future source for oil may be found in __?__.
8. Metals are heavy elements that conduct electricity and are __?__.
9. Diamond is made of the element __?__.
10. The amount of __?__ used by a nation is said to indicate its industrial activity.

D. How and Why

1. Why was it natural for early men to choose flint for weapon making?
2. How do you suppose early men discovered that clay can be shaped into fairly permanent dishes and containers?
3. Why was copper in its native form a natural choice as the first metal used by primitive man?
4. Discuss the relative importance of metals and nonmetals in today's world.
5. Why are veins of copper, gold, and most other metals found near rock bodies of igneous origin?
6. How is copper concentrated by water?
7. Why is anthracite coal more valuable than lignite?
8. Why is oil shale not used extensively as fuel at present?
9. Discuss conditions under which a presently low-grade mineral deposit might become an ore.
10. Silver and gold are often recovered as by-products during the refining of lead or copper. What effect does the presence of silver and gold have on the grade of ore that can be profitably mined?

INVESTIGATIONS

1. Prepare a display of tools and weapons of the Stone Age. You might include pictures of modern weapons and some modern tools for a distinct contrast to your Stone Age tools and weapons.

2. List at least 15 lithospheric materials which you have observed in use in your home or in a public building. Tell where you saw each material used.
3. Choose one of the following topics for an oral report. Use library references to research your topic.
   (a) Quarrying and using: marble, limestone, slate, granite, sandstone.
   (b) Source of supply, manufacturing, and using steel.
   (c) Mining or producing: iron, copper, gold, silver, diamonds, salt.
   (d) Locating and drilling oil wells.
   (e) Procuring and using commercially: flint chert, peat, coal, gypsum, anhydrite, coral, mica, kaolinite, oil shale.
   (f) Preparing and marketing any gem.
   (g) Producing, transporting (include information on modern pipe lines), marketing, and storing natural gas.
   (h) Using petroleum in manufacturing plastics or rubber.

INTERESTING READING

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Reinfield, F., *Uranium and Other Miracle Metals.* New York: Sterling Publishing Co., Inc., 1955.

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The Atmosphere and the Hydrosphere

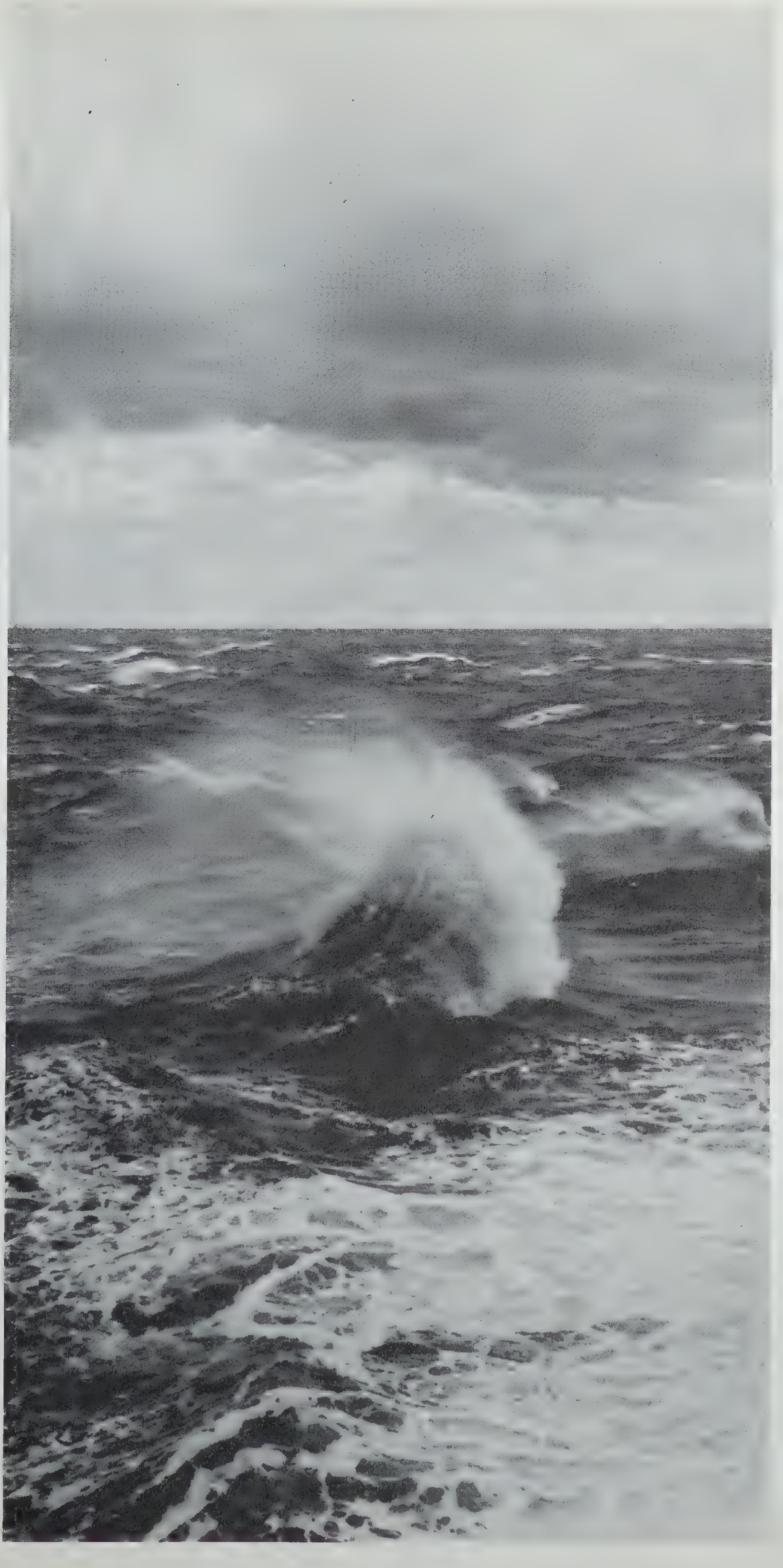
. . . consider the wonderful changes . . . in the interior and at the surface of the earth, in all its productions, in the constitution and pressure of the atmosphere, in the ocean . . .

Pierre Laplace (1749-1827)

It is not surprising that Aristotle and other ancient scholars believed air and water were basic elements of the physical universe. The two oceans, one of air and one of water, which surround the land are essential to life. Planets without atmosphere are barren; land areas without water are deserts.

Air and water complement one another in supporting life, in shaping the earth's surface, and in determining climates of the earth. Air penetrates the soil and surface rock and is dissolved in all the waters of land and sea. It is truly the breath of life. Water evaporates into the air, becomes part of the protective envelope which shelters earth from space debris, and returns to the land as moisture to support and nourish life. Air and water together control earth's weather and determine earth's climates. Weather and climate are the most important factors in man's natural environment.

Meteorologists, the scientists who study atmospheric conditions, are steadily becoming more important in this modern age. These scientists forecast weather, warn of catastrophic storms, and compare atmospheric conditions around the globe. Space travel and exploration would be impossible without the aid of meteorologists. Oceanographers specialize in the study of the oceans, the topography of sea bottoms, the constitution of seawater, and the inhabitants of the deeps. In the future, oceanographers may become agricultural advisors as the need to turn to the oceans for food increases. These two scientific fields related to the atmosphere and the hydrosphere are expanding and vital to the future of man.



UNIT Three

9 The Atmosphere

Air is a mixture of gases. It contains oxygen which is used by plants and animals, carbon dioxide which is used by plants, and water vapor which is used by both animals and plants. Air also serves as a blanket that protects the earth from extreme heat and cold and from meteors that fall from outer space. Earth is not a barren planet because its air supports and protects life. Some elements necessary to life are supplied directly by the air. Other life-supporting elements are released during chemical reactions between air and rocks.

9:1 *Atmosphere of the Earth*

The **atmosphere** is an ocean of air surrounding the earth and extending into space for about 100,000 miles.

Earth is surrounded by a huge mass of gases called the *atmosphere* (at′mu sfir). No other planet is known to have a similar atmosphere, although many scientists believe that such planets may exist beyond our solar system. Earth's envelope of air is essential to life. Yet man is seldom aware of the importance of air until it is polluted with dust or smog.

The atmosphere extends outward for approximately 100,000 mi, and downward for hundreds of feet through rock openings that connect with the surface. Air is also dissolved in inland lakes and open oceans. Air and water cause chemical changes and physical changes in surface rocks where the lithosphere, atmosphere, and *hydrosphere* (hie′dru sfir) are in contact.

EXPERIMENT. Fill five glasses with water. Set one glass in the sun and a second glass in the shade. Gently drop a small piece of earth into the third glass, a small piece of porous brick into the fourth glass, and a piece of granite into the fifth glass. What rises to the top of the glass when earth and brick are dropped into the water? What happens when the granite is added to the water? Explain your answer. Now look at the

glass of water that was warmed by the sun. Explain what has happened. Examine the glass that was in the shade. Are any air bubbles present in that glass? Why?

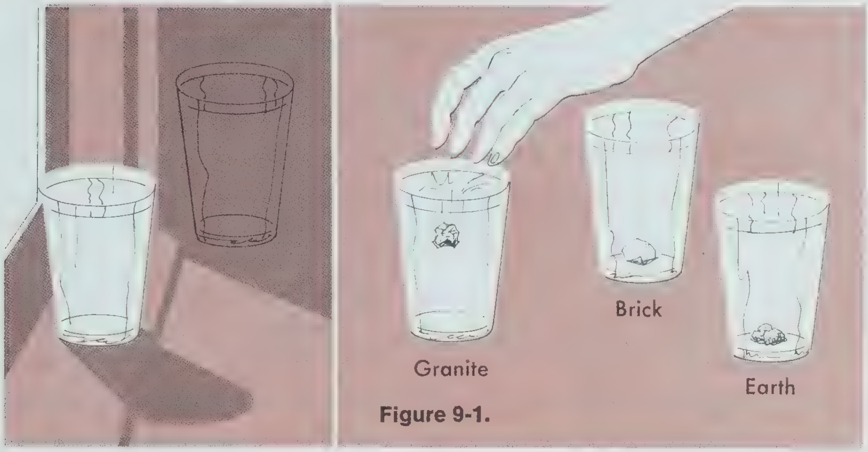


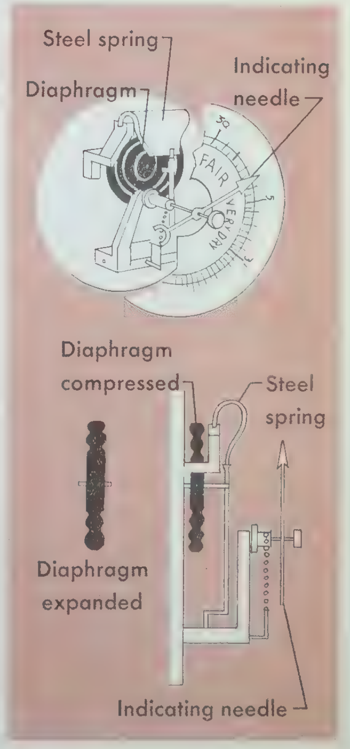
Figure 9-1.

9:2 *Air Pressure*

Earth's atmosphere consists of gases which cannot be seen. But the gases have volume and weight and, therefore, exert pressure on the lithosphere. At sea level, the weight of one cubic foot (1 ft^3) of air is approximately one ounce (1 oz). At sea level, the gas molecules are packed closely together because the weight of the air above the molecules compresses the air at sea level. Air pressure decreases with increases in altitude because molecules are freer to move and fewer molecules are present within a given volume of air.

Air pressure is measured by an instrument called a *barometer* (ba rahm′et er). The principle of an **aneroid** (an′e rawid) **barometer** is similar to that of a bathroom scale. When you step on a bathroom scale, your weight exerts pressure on a spring. A needle attached to the spring moves across a scale of numbers and records the amount of pressure in terms of your weight. In an aneroid barometer, a metal *diaphragm* (die′a fram) forms the top of a box from which air has been removed. This diaphragm is supported by a spring. When air pressure, the force exerted by the weight of a column of air above the barometer, depresses the diaphragm, the spring's tension is overcome and it moves. This movement is indicated by a needle which is attached to the spring. The needle moves across a scale which indicates the amount of pressure exerted by the air column.

Figure 9-2. In this cutaway view of an aneroid barometer, the needle responds to compression of the diaphragm.



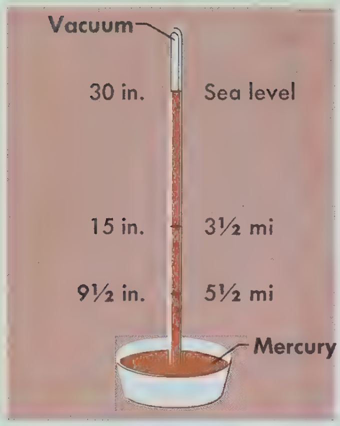


Figure 9-3. Increased air density is indicated by the increased height of the mercury column at sea level.

Units on a **mercury barometer** are based on the height in inches that a column of mercury rises in a closed tube. (Figure 9–3.) An open end of the tube is inserted in a dish of mercury. Mercury rises in the tube due to the air pressure exerted on the mercury that surrounds the tube. Because the space above the mercury in the tube is a vacuum and the tube is closed at the end exposed to the air, the mercury within the tube is protected from air pressure. The height of the mercury is read on a scale which indicates the amount of pressure exerted by the column of air above the exposed mercury. Normal readings on a mercury barometer are approximately 30 in. at sea level, 15 in. at an altitude of 3½ mi, and 9½ in. at 5½ mi above sea level (the elevation of Mt. Everest). Barometric readings vary from time to time for any given place because of temperature changes and wind movements. Pressure exerted by air at sea level is approximately 15 pounds for every square inch of surface (15 lb/in.^{2}).

EXPERIMENT. Hold an empty bottle upside down, and force it below the surface of water in a large pan. Be sure to keep the bottle vertical. Try the same thing with an empty glass. Does the water fill the glass or the bottle? What properties of air have you discovered in this experiment?

Figure 9-4.

EXPERIMENT. Attach a string to the center of a long, straight stick such as a yardstick. Be sure that the stick balances when you hold it up by the string. Inflate two balloons of the same size. Tie their openings with strings of the same length. Suspend a balloon from each end of the balanced stick. Keep the stick level and make certain that the balloons balance. Now touch a long, lighted match, preferably a fireplace match, to one balloon. What happens? Explain.

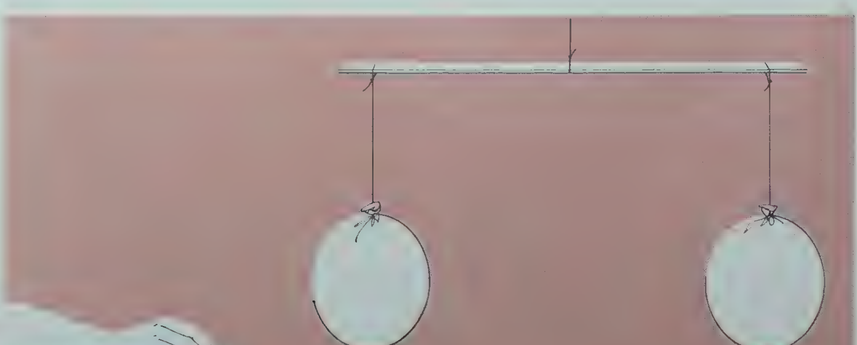


Figure 9-5.

EXPERIMENT. Place a container half full of water at a higher level than an empty container. Bend a flexible drinking straw or a small rubber tube into a U shape. Fill the tube with water from the faucet. Put a finger over each end of the tube and carefully insert one end in each of the containers. Remove your finger from the end, and let the tube hang on the side of the higher container. What happens to the water? Why? What are some practical applications of this siphoning *(sief′uh ning) process?*

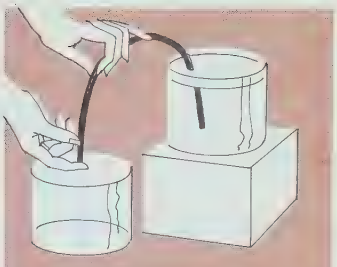


Figure 9-6.

9:3 Composition of the Atmosphere

Air is a mixture of gases. *Nitrogen* (nie′tra jen), *oxygen*, *carbon dioxide*, and *argon* (ahr′gahn) are always present. Water vapor and traces of other gases are also present in small amounts. Dust particles are suspended in the spaces between molecules of gas.

Nitrogen makes up 78 percent of the atmosphere. Free nitrogen is not chemically active; that is, it seldom combines with other elements. Occasionally, lightning provides enough heat energy to cause free nitrogen of the air to unite with oxygen. But the major effect of the nitrogen in the air is to prevent the rapid uniting of oxygen with other substances in the process called burning. Nitrogen compounds enter the soil and nourish plant life. Soil algae and nitrogen-fixing bacteria, which live within the roots of plants called *legumes* (le′geums), produce nitrogen compounds in a form that can be used by plants. Animals eat the plants and return nitrogen compounds to the soil in their body wastes. Nitrogen compounds also are added to the soil during decay of plants and animal matter.

USDA Photo

Figure 9-7. The characteristic nodules on the roots of leguminous plants are caused by the nitrogen-fixing bacteria which live within them.

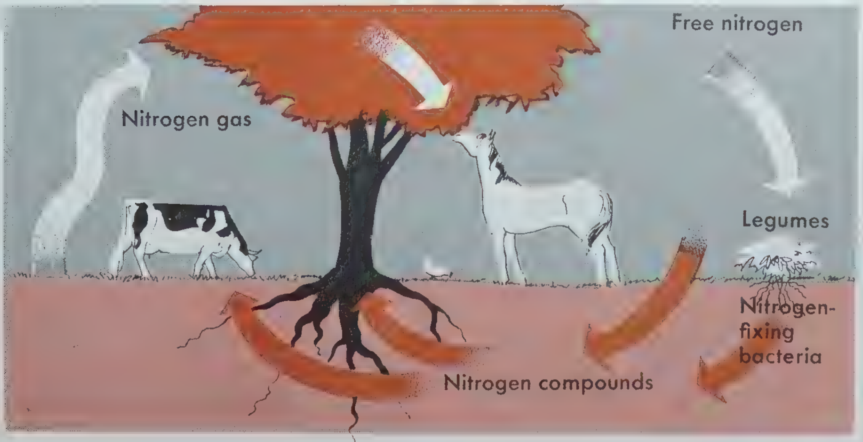


Figure 9-8. Both plants and animals utilize the nitrogen compounds produced by the nitrogen-fixing algae and bacteria in the soil and return nitrogen to the soil or air after death.

Oxygen constitutes 21 percent of the air and is essential to various life processes. Land animals take oxygen directly from the air; marine animals take dissolved oxygen from seawater. During burning, oxygen combines rapidly with other substances. During the decomposition of rocks, oxygen combines slowly to form new compounds. But the amount of oxygen in the air remains relatively constant because plants release oxygen during their life processes.

The small amount of argon in the air dilutes the oxygen and consequently slows decay.

Argon constitutes 0.93 percent of the air. Like nitrogen, argon is not chemically active; it does not combine readily with other substances. Argon in the atmosphere dilutes the amount of oxygen and, thereby, prevents rapid decay.

Although carbon dioxide is present in the air in small amounts, it feeds plants and insulates the earth against loss of heat.

Carbon dioxide composes 0.03 percent of the atmosphere. Plants convert carbon dioxide released by animals to organic matter and give off oxygen. Without carbon dioxide there could be no plant life; without oxygen there could be no animal life. Carbon dioxide also helps to conserve the earth's heat. It prevents the escape of much of the heat that is radiated to earth from the sun.

Water vapor serves as insulation and furnishes needed humidity for plants and animals.

Water vapor is present in the atmosphere in small, variable amounts. Like carbon dioxide, water vapor prevents the loss of heat from the earth. Water vapor enters the air through *evaporation* from bodies of water, and also through *transpiration* (trans pa rae′shun), the emission of water from plant surfaces. Water returns to the surface of the earth as rain, snow, sleet, or hail, or it condenses on cool surfaces as dew or frost.

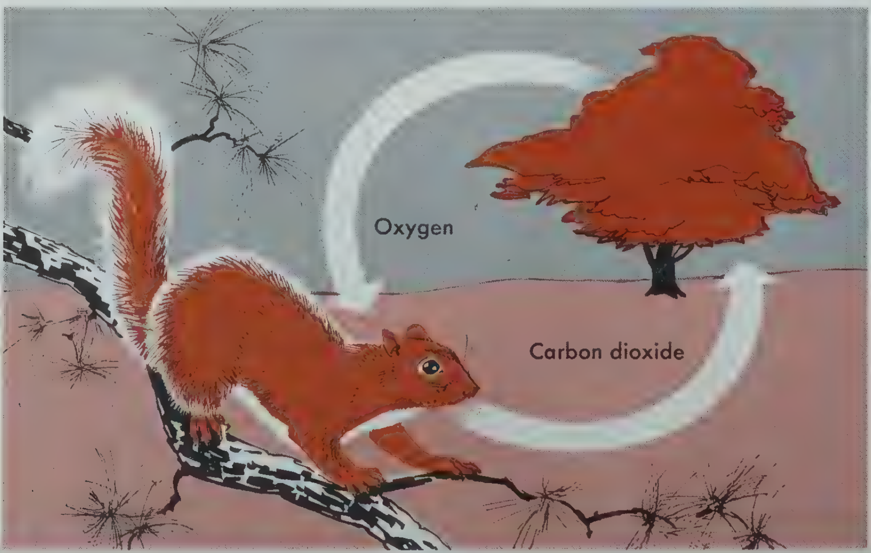


Figure 9-9. Plants and animals supply each other with substances necessary for their life processes.

PROBLEM

Make a chart showing the comparative percentages of the components in the air. Does your total equal 100 percent? What components should you add to make 100 percent?

9:4 *Structure of the Atmosphere*

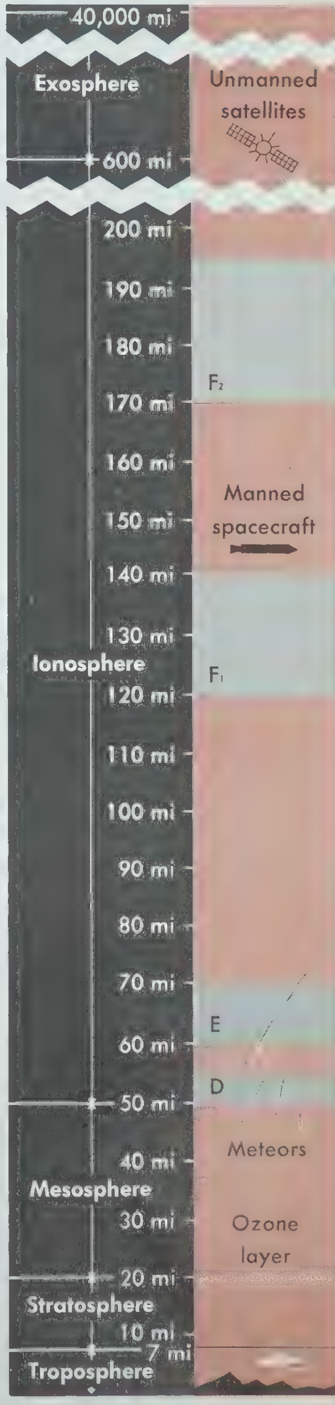
Five layers have been recognized in the atmosphere. Each layer has different characteristics. Closest to the earth is the *troposphere*, then the *stratosphere*, the *mesosphere*, the *ionosphere*, and finally the *exosphere*. These layers are of variable thickness and blend into one another. Much information has been gathered about the troposphere and the stratosphere because these layers have been investigated for many years. Recently, satellites and rockets have made it possible to reach the upper atmosphere and obtain information, but much remains to be discovered.

The **troposphere**, the layer of air in which you live, extends only 7 mi above the earth. But it contains 75 percent of the gases of the atmosphere. Air is most dense at sea level, due to the weight of the gases above. As altitude increases, density of the air decreases. People who live at high altitudes often develop greater lung capacity than those who live at sea level. At high altitudes, they must breathe more often and more deeply to obtain the necessary amount of oxygen. Modern planes fly at altitudes of approximately 6 mi. At such heights, the air is very thin and planes require pressurized cabins and extra supplies of oxygen for emergencies. Pressurized cabins in planes and pressurized suits for astronauts are designed to maintain an oxygen concentration necessary to support life processes. The human body can adjust its internal pressure to outside pressure. But if the outside pressure is suddenly lowered, the body must be protected from the sudden change.

Beyond the troposphere is the **stratosphere** which extends from 7 mi to about 20 mi above the earth. Air in the stratosphere is dry, cold, and exceedingly thin. Temperatures are relatively constant at $-54°C$ ($-65°F$). Temperatures vary so little in the stratosphere that there is almost no air movement. Because most water vapor is condensed within the troposphere, few clouds are present in the stratosphere.

The **mesosphere** extends from about 20 mi to about 50 mi above the earth. Its temperature of 77°C (170°F) makes the

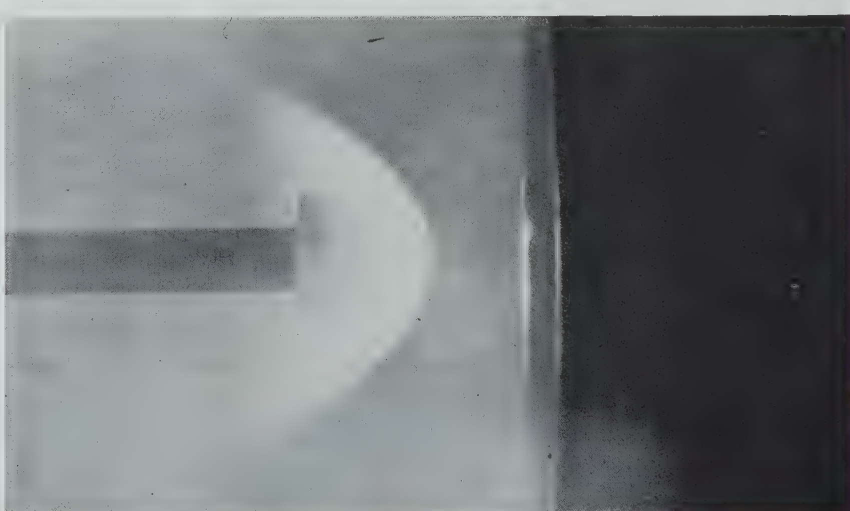
Figure 9-10. Earth's atmosphere decreases in density with distance from earth because particles are farther apart. In D, E, F_1, and F_2 Zones particles have been ionized by radiation from the sun.



The **mesosphere** is a 30 mile band, has extremely high temperatures, and protects the earth from ultraviolet rays and space debris called meteors.

mesosphere a dangerous zone for spacemen. Space capsules must be protected from frictional heating by specially designed heat shields for their reentry to earth's atmosphere. Several space explorers have described the fiery glow given off by the heat shield of a space capsule as it passes through the mesosphere.

In large amounts, *ultraviolet rays* can cause death. However, they are beneficial in small doses. In the mesosphere, ultraviolet rays change free oxygen to *ozone* (O_3), a form of gas containing three atoms of oxygen in each molecule. Ordinary oxygen (O_2) in the troposphere contains only two atoms in each oxygen molecule. Ozone in the mesosphere absorbs ultraviolet rays and changes them so that they are harmless when they reach the earth. Thus, the mesosphere protects the earth from excessive ultraviolet radiation.



Ohio State University

Figure 9-11. A simulated heat shield glows in the high temperatures expected in the mesosphere.

Heat in the mesosphere also protects the earth from large quantities of meteoric material. *Meteoroids* are the dust and rubble of outer space. They may be pieces of exploded stars or they may be original space matter that has never been a part of stars or planets. Most meteors are melted and burned in the layer of ozone in the mesosphere. *Shooting stars* are not stars at all, but are meteors burning in the mesosphere. Occasionally, a meteor reaches the earth, but most meteors are burned up 40 mi or 50 mi above the earth. *Meteorites*, the name given to meteors that reach earth, travel with a velocity up to 40 mi/sec. Meteorites may do great damage when they collide with earth.

The **ionosphere** begins about 50 mi above the earth and extends outward for 500 mi to 600 mi. In the ionosphere, radiation from the sun changes the gas atoms into electrically charged particles called *ions.* (Section 3:3.) At this height, the air is so thin that objects passing through the ionosphere do not become heated.

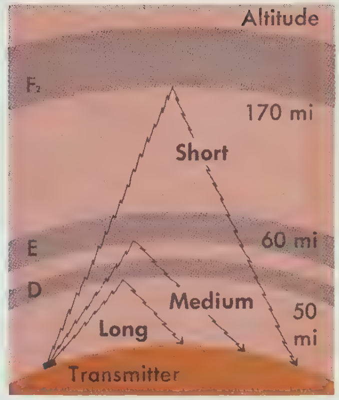


Figure 9-12. Ionized particles of the D, E, and F_2 Zones reflect radio waves toward earth.

Although molecules in the ionosphere are too far apart to affect objects moving through the zone, radio waves from the earth which come in contact with the rapidly moving ions are bounced back to earth in much the same way that a ball is bounced back from a wall. Radio waves are reflected from the ionosphere at an angle and return to earth far from their point of origin. Radio reception is disrupted temporarily from time to time as the position of the ionized layers shifts. Shifts of the ionized layers are due to changes in the sun's activity.

At the greatest distance from the earth is the layer called the **exosphere.** The exosphere begins about 500 mi to 600 mi above the earth with a band of helium gas approximately 900 mi thick. This helium-rich band is surrounded by a layer of hydrogen gas which extends outward for possibly another 40,000 mi. Little is known about the exosphere except that it contains radioactive particles which originated in the sun. In 1958, Dr. James Van Allen, an American physicist, identified bands of radiation in the exosphere. These bands are now known as the *Van Allen belts.* Radioactive particles in the exosphere would be as dangerous to life as radioactive fallout from a nuclear bomb. Most manned space orbits have been below the exosphere, but unmanned rockets have been sent through this layer.

The **exosphere**, the most distant layer, is a band of helium 900 miles thick surrounded by hydrogen which may extend for another 40,000 miles.

Van Allen belts in the exosphere are bands of radiation which have been explored with rockets.

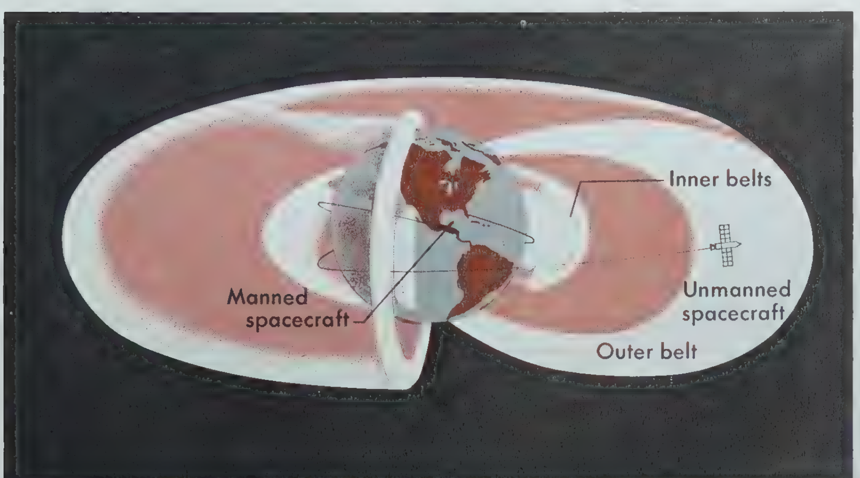


Figure 9-13. Unmanned rockets have penetrated the exosphere and encountered bands of radioactive particles.

Beyond the exosphere, gases may be somewhat more concentrated than they are in outer space. Scientists know very little about the atmosphere above 40,000 mi, but the outer limits of the atmosphere may be as distant as 100,000 mi. Above 40,000 mi, molecules of gas are so widely separated that the exosphere is often considered the outermost layer of the atmosphere.

PROBLEMS

1. Make a scale diagram of the layers of the atmosphere surrounding the earth. If you find it impossible to represent the true relationship among the various zones, explain the reason for your difficulty.
2. Make a separate chart of the troposphere showing the relative densities of air at various altitudes.

9:5 *Heat*

Radiant energy from the sun that is absorbed by the earth is transformed from light rays and infrared rays into heat.

Heat that strikes earth and atmosphere comes from the sun. It is thought that the sun emits a fairly constant amount of *radiant energy* in the form of waves. These waves may pass through the atmosphere and reach the earth in much the same way that light from a lamp travels across a room. However, the amount of radiant energy that reaches the earth is affected by several factors. Some radiant energy is reflected into space by gas molecules; some is reflected by dust particles in the air; some is reflected by clouds; and some is absorbed by ozone in the mesosphere. Radiant energy that is reflected into space is lost and never reaches the earth.

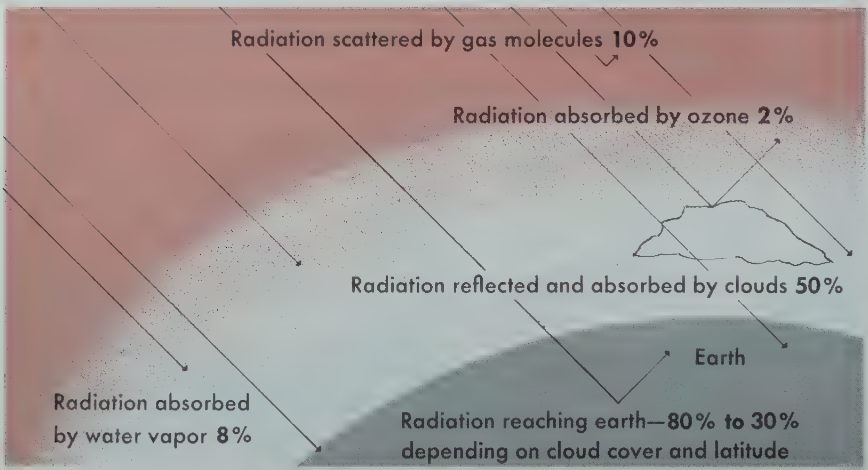


Figure 9-14. A varying percent of the sun's radiant energy reaches earth through the protective blanket of the earth's atmosphere.

Radiant energy that reaches the earth is absorbed and changed into heat, or *infrared waves.* Different areas of the earth absorb different amounts of heat for various reasons. At the poles, much of the radiant energy is reflected into the atmosphere by ice. Little of the sun's energy is converted to heat in the polar regions. Oceans also reflect more of the sun's energy than is reflected by land. Dark areas of the earth absorb more heat energy than other areas. However, land areas tend to lose their heat to the atmosphere more readily than oceans do. Radiant energy that is absorbed by the earth and converted to heat becomes a source of heat for the atmosphere. Heat would be lost at night if it were not for the atmosphere—like the moon, the earth would have extreme differences between day and night temperatures.

Differences in the surface of the earth cause differences in heat absorption.

Carbon dioxide and water vapor are most effective in keeping heat near the earth. They absorb heat and reradiate it toward the earth. Few infrared waves are reflected toward the earth if water vapor and carbon dioxide are absent from the atmosphere. Instead, heat is lost to outer space. Deserts and mountain regions, where water vapor is absent, lose more heat at night than is lost in humid regions. To some extent, gas molecules also help retain heat. On high mountains, where gas molecules are far apart, more heat is lost than in adjacent valleys.

Heat for the atmosphere comes indirectly from the sun, but directly from the earth. Processes of heating the atmosphere are similar to processes used in heating homes. Heat is transferred from one body to another by *radiation*, *conduction*, and *convection.*

Figure 9-15. Waves of heat flow outward from a warm body toward a cold body.

Radiation is the process by which heat from a warm mass is transferred to a cold mass by heat waves. Heat flows in waves from the warm mass and causes the molecules of the cold mass to move more rapidly. The increased velocity of the molecules raises the temperature of the cold mass. Eventually both masses reach the same temperature. Radiation ceases when molecules of both masses are moving with the same velocity.

Fireplaces radiate heat. Although you do not touch the fire, your body is warmed on the side turned toward the fire because that side absorbs heat waves. However, this method of heating is not efficient because it does not distribute heat beyond the immediate area of the fire.

When the sun sets, a portion of the earth and its atmosphere no longer receives heat from the sun. The atmosphere begins to lose heat more rapidly than the earth. Thus, the earth remains

warmer than the air. Earth then radiates heat into the atmosphere and, as the earth cools, dew forms on the cold soil and plants. *Dew* is moisture from the air that condenses when it comes in contact with the colder earth. *Frost* forms if the temperature is below freezing. Frost occurs on cold, clear nights when heat is lost rapidly from the earth. If a cloud cover is present, heat radiated from the earth to the atmosphere is reradiated to the earth, and frost is less likely to form.

EXPERIMENT. Fill an empty glass with ice cubes and water. Set it in a warm place and stir. Place another glass of water in the sun. What happens on the outside of each glass? From what you have observed, explain why dew forms on clear nights. Put the glass covered with moisture in front of an operating electric fan. What happens after several minutes?

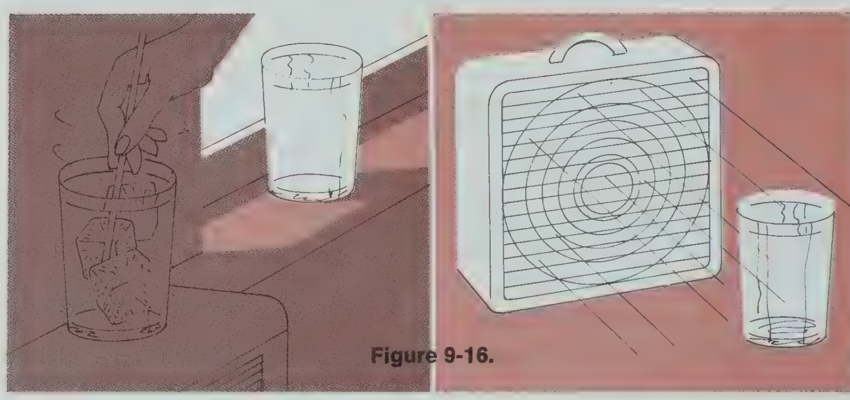


Figure 9-16.

PROBLEMS

1. The *dew point* is the temperature at which dew forms on an object. What factors influence the dew point?
2. The *relative humidity* in Phoenix, Arizona, is normally 10%. Explain what this figure means.
3. The relative humidity in Houston, Texas, is often 70% to 80%. At which location, Phoenix or Houston, would a greater drop in temperature be required for dew to form?
4. Why does dew or frost form on clear, still nights rather than on windy nights, even though the temperature may be lower on windy nights?

Heat by conduction requires contact of molecules.

Conduction (kan duk′shun) is the process by which heat from one mass is transferred to another mass through actual contact of molecules. Molecules of air in contact with the earth

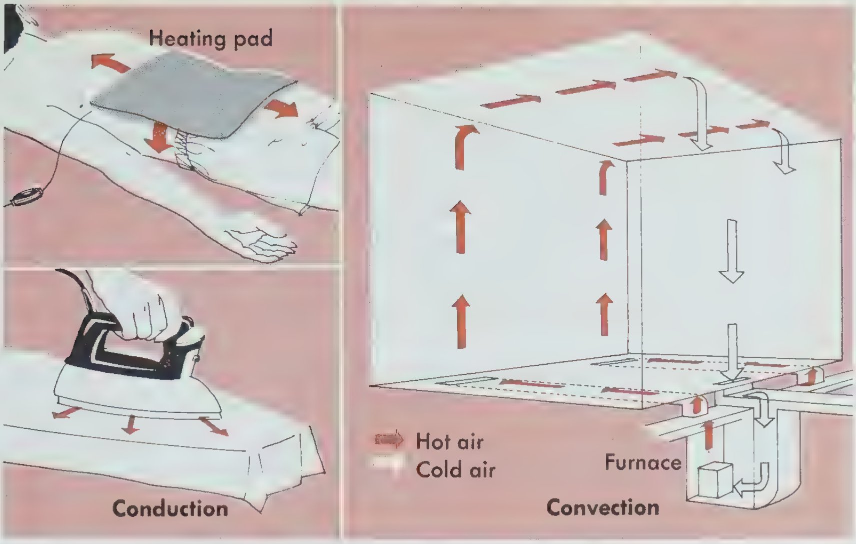


Figure 9-17. Heat may be transferred by direct contact or by circulating currents of warm air.

receive heat from the surface of the earth. Heat passes from molecule to molecule. Then molecules pass the heat to the cooler molecules above them, until all molecules reach the same temperature. Because both rocks and air are poor conductors of heat, this process is relatively unimportant in heating the atmosphere.

An example of heating by conduction is the transfer of heat to molecules of your skin when you touch a stove. Heating pads and hot water bottles warm a small area of your body by conduction, but the rest of your body is not affected.

In convection heating, air is warmed, rises, is replaced by cool air, is cooled, and sinks again until heat is evenly distributed.

Convection (kan vek′shun) is the transfer of heat energy by actual movement of heated matter. It is the most effective method of heating the atmosphere. Air near the surface of the earth is heated by radiation and conduction. As the air is warmed, its molecules tend to move farther and faster. Molecules are farther apart in warm air than in cold air and, therefore, warm air is less dense than cold air. Warm air rises and the heavier cold air flows in to replace it. *Convection currents* cause a constant exchange of air masses until heat is distributed equally over a wide area.

Most modern heating systems use the principle of convection to distribute heat. Air which has been heated by a furnace flows into a room, usually near the floor. Air in the path of the warm air is heated, and the warm air rises toward the ceiling, replacing cool air. Meanwhile, cold air moves downward toward the floor, where it too is heated. In efficient heating systems, cold air flows out of the room through cold air ducts. Warm air continues to rise and cold air to descend until all air in the room is heated to nearly the same temperature.

EXPERIMENT. *Fill a bottle with cold water. Record the temperature of the cold water with a thermometer. Set the bottle in direct sunlight. After one hour, record the temperature again. Is it the same? If not, account for the difference. Record the temperature in your notebook and indicate the method by which the water was heated.*

Heat a small pan of water over a Bunsen burner. Place a metal spoon in the pan and hold onto the handle. What happens? Why?

Place a thermometer on the floor. Allow it to remain there for a few minutes and then record the temperature in your notebook. Then take a reading at your desk, and record it in your notebook. Place the thermometer as close as possible to the ceiling. After a few minutes, read the temperature and record it. Is the temperature higher near the ceiling? Why? What is the temperature about halfway between the ceiling and the desk? Discuss the method by which the room is heated.

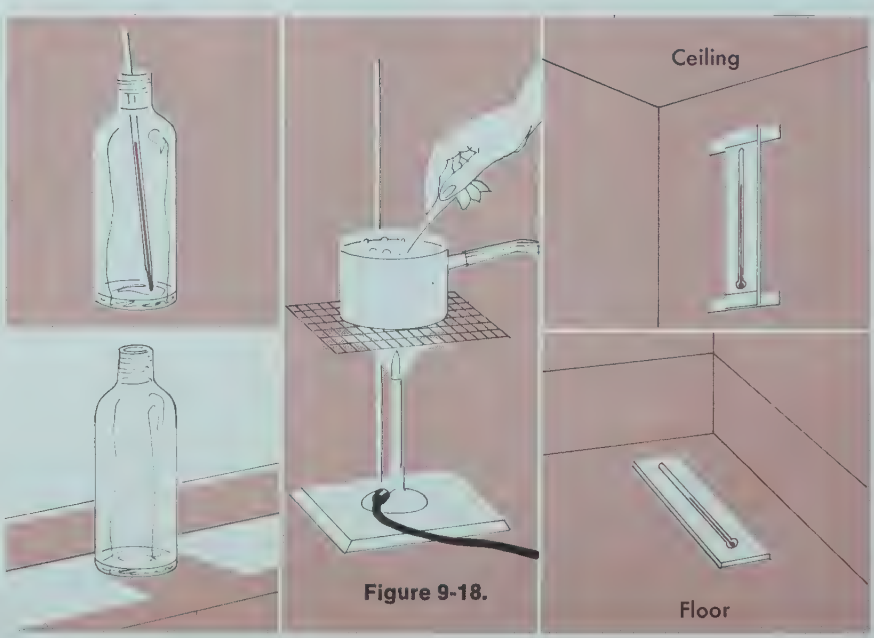


Figure 9-18.

9:6 *Seasons*

Giant convection currents in the atmosphere tend to distribute heat evenly around the earth. In spite of these convection currents, some regions of the earth are always hot, some regions are always cold, and other regions have alternate seasons of

warm summers and cold winters. The amount of radiant energy emitted by the sun is relatively constant. But the amount of heat received on earth varies with the length of daylight and the angle at which the sun's rays strike the earth.

Heat distribution depends upon the length of time and the angle at which the sun's rays strike various areas.

Recall that the earth turns on its axis once every 24 hours. The earth revolves around the sun once in approximately 365 days. Variations in the amount of daylight and the angle of the sun's rays are due to these motions of the earth. (Section 1:4.) There would be no seasons if it were not for the earth's motions and the tilt of the earth's axis from a line vertical to its orbital plane.

As the earth rotates on its axis, the side facing the sun is in daylight; the side away from the sun is in darkness. If the earth's axis were vertical to its orbital plane, the number of daylight hours would always be the same for any given latitude. But because the earth's axis is tilted 23½° from the vertical to its orbital plane, the number of daylight hours varies throughout the year for any latitude. From March to September, the north pole is tilted toward the sun. From September to March, the south pole is tilted toward the sun. The seasons in the southern hemisphere are the opposite of those of the northern hemisphere. The northern hemisphere has summer, and the southern hemisphere has winter, when the north pole is tipped toward the sun. When the south pole is tipped toward the sun, the southern hemisphere has summer and the northern hemisphere has winter. (Figure 9–19.)

Because of the tilt of the earth's axis and revolution and rotation, different areas receive varying amounts of exposure to the sun.

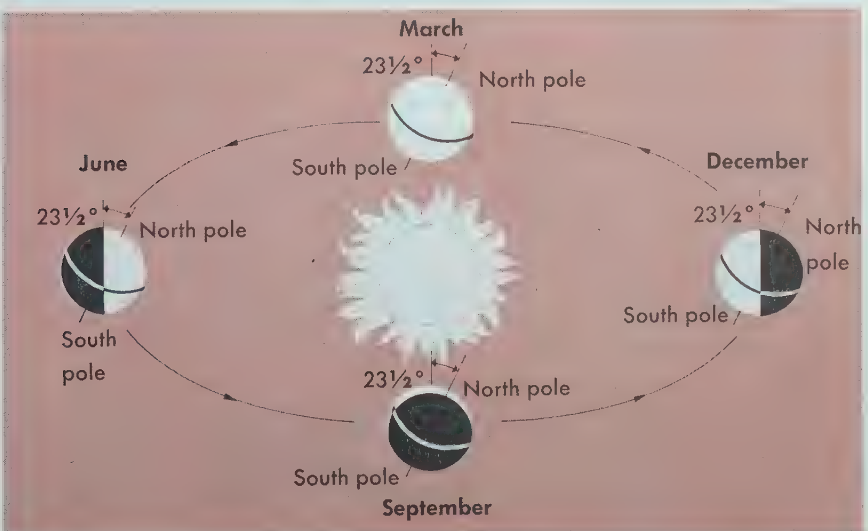


Figure 9-19. The amount of radiation received at different latitudes varies with the position of the earth in its orbit.

When a pole is tipped toward the sun, the polar region has 24 hours of daylight. When a pole is tipped away from the sun, the polar region has darkness for 24 hours. At the equator, day and night are always of equal length. Between the equator and the poles, the length of daylight or darkness ranges from a few seconds to 24 hours, depending on latitude and time of year.

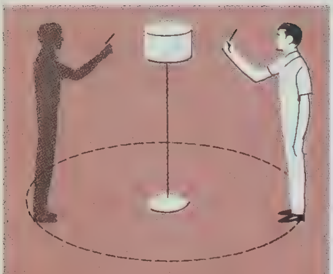


Figure 9-20.

EXPERIMENT. Hold a pencil 23½° from a vertical line to the floor. Keep the pencil at this angle and pointed toward the same place on the ceiling as you walk in a circle around a lamp. Compare the amount of light that falls on the eraser end of the pencil with the amount that falls on the pencil point. Are there any positions in which the amount of light received by both ends is approximately equal? Explain your answer.

Hours of sunshine only partly determine the amount of radiant energy received by the earth. Another important factor that influences the amount of energy received by the earth is the angle at which the sun's rays strike the earth. The more atmosphere the radiant energy passes through, the more energy is lost before it reaches the earth. The more surface that a given amount of radiant energy strikes, the less heat per unit of area is transferred to the earth. Rays of the sun that strike the earth at 90° pass through the least amount of air, bring the most radiant energy to the earth, and cover the smallest surface area. Rays of the sun that strike the earth at angles of less than 90° pass through more atmosphere, loose more energy, and transfer less heat per unit area as the angles decrease.

If the earth did not tilt on its axis, the sun's rays would always strike the equator at 90° and strike the poles at 0°. Rays would strike other latitudes at angles ranging from 90° to 0°. Because the earth's axis is tilted from the vertical to the plane of orbit, the direct rays of the sun do not always strike the earth at the equator. As the earth moves around the sun, the direct rays shift gradually from the equator to 23½° north latitude between March and June. From June to September, the direct rays move back toward the equator. From September to December, the direct rays shift toward 23½° south latitude and, from December to March, the direct rays move back toward the equator. (Figure 9–19.) Twice each year the direct rays of the sun are at the equator. At no time do the sun's rays strike the equator at less than 66½°.

EXPERIMENT. Find the center of an 8-in. square block of wood by drawing diagonals across one surface. From the center point, draw a straight line to the center of one edge of the wood block. Place the block in the sun where it will not be disturbed. Using a compass, locate north and arrange the block with the straight line pointing due north. Drive a nail into the center of the block so it casts a shadow on the block of wood. Check the time and mark the hours on the block as indicated by the shadow. Check the sundial the next day. Is it still telling the correct time? After a few weeks, does the sundial still indicate the correct time?

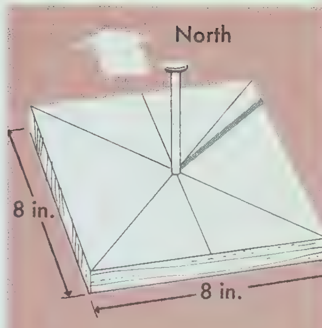


Figure 9-21.

The zone in which the sun's rays strike the earth most directly lies from 23½° south of the equator to 23½° north of the equator. This zone is known as the *tropics.* The northern boundary of the tropics is the latitude called the Tropic of Cancer. The southern boundary is the latitude called the Tropic of Capricorn. *Temperate zones* lie between 23½° and 66½° latitude both north and south. *Frigid zones* lie from 66½° latitude to 90° at the poles. (Figure 9–22.)

The Tropics of Cancer and Capricorn at 23½° north and south of the equator are the boundaries of the area of the sun's direct rays.

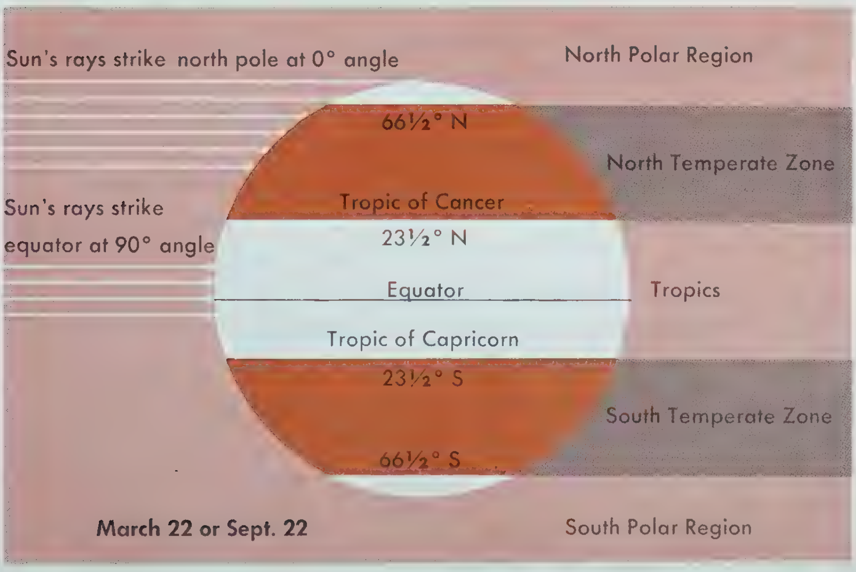


Figure 9-22. Rays from the sun are perpendicular to the equator and days and nights are of equal length throughout the earth at the spring and autumnal equinoxes.

Polar regions have 24 hours of daylight part of the year, but they remain cold because the rays of the sun strike the region at such small angles. Furthermore, the ice cover tends to reflect much of the heat received during the summer season. Heat is lost continuously during the period of darkness.

Temperate zones lie between 23½° and 66½° latitude north and south. The polar zones lie north and south of the 66½° latitudes.

PROBLEM

1. On a map that gives latitude and longitude, determine the zone in which you live.
2. Does any place in continental U. S. ever receive the rays of the sun at 90°? Why? What city comes closest to receiving the direct rays of the sun? What is the latitude of this city? Estimate the approximate angle at which the sun's rays strike this city on June 21.
3. What is the angle of the sun's rays that strike Rio de Janeiro, Brazil, on December 21?

Climates are classified according to presence of water vapor, temperature range, wind direction, and air pressure.

Climate is the term used to refer to weather conditions over long periods of time and in large areas. **Weather** refers to day-to-day changes in temperature, wind, and humidity. Weather is so variable and complex that it requires detailed discussion. (Chapter 10.) Weather records of ten or more years are averaged to determine the climate for a given area. Conditions considered in determining weather and climate include the amount of water vapor, range of temperature, kind and direction of wind movements, and variations in air pressure.

Climatic regions blend into one another, but geographers divide the earth into three general types, which agree with the three seasonal zones. North and south *polar climates* lie in the frigid zone; *temperate climates* are characteristic of the temperate zone; *tropical climates* are typical of the tropical zone. Within these three regions, local climatic conditions also occur. They include *marine climates* along shore zones, *continental climates* in the interior of the continents, and *mountain climates* and *desert climates* in limited regions of the continents. Climate for any region depends upon its location, the amount of radiant energy received from the sun, and the circulation pattern of the atmosphere.

MAIN IDEAS

1. Earth's atmosphere is a layer of air, perhaps 100,000 mi in extent, held in place by the earth's gravity.
2. The atmosphere, which is necessary to life, has weight and exerts pressure. Pressure and weight decrease as distance from the surface of the earth increases.
3. Air pressure is measured by a barometer and is 15 lb/in.^{2} at sea level.

4. Air is composed of the gases nitrogen, oxygen, carbon dioxide, argon, and water vapor plus suspended dust particles.
5. Nitrogen nourishes plants; oxygen sustains life; carbon dioxide feeds plants and conserves the heat of the earth; argon dilutes the oxygen; and water vapor insulates and provides humidity.
6. Scientists have concluded that the atmosphere is composed of five indistinctly separated layers.
7. The layer in which you live, the troposphere, extends outward for about 7 mi and contains almost three-fourths of the gases of the atmosphere.
8. The second layer, the stratosphere, extends from about 7 mi to about 20 mi above the earth. The air in this zone is quiet, cold, dry, and thin.
9. Beyond the stratosphere lies the mesosphere, a band of ozone about 30 mi thick, which protects the earth from ultraviolet rays and showers of meteoritic fragments.
10. In the ionosphere, extending from the mesosphere for about 500 mi to 600 mi, atoms are changed to ions by radiation. These electrically charged particles reflect radio waves back to earth at some distance from their point of origin.
11. Little is known about the exosphere, the most distant layer of the atmosphere, except that it contains the Van Allen belts, which consist of bands of dangerous radioactive particles.
12. The atmosphere and the earth are heated by radiant energy from the sun when infrared rays and light rays are absorbed by the earth. Absorption depends upon the water vapor and carbon dioxide present in the atmosphere and upon the surface conditions of the earth.
13. Heat is transferred to the atmosphere by radiation (waves of energy), conduction (contact of molecules), and convection (exchange of air currents).
14. Exposure to the sun's rays and the angle at which the rays strike different regions depends upon revolution and rotation of the earth and the tilt of the earth's axis.
15. Changing seasons and climatic zones are due to differences in the amount of sunshine received, and in the angle at which the sun's rays strike the earth.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

atmosphere	hydrosphere	stratosphere
barometer	ionosphere	temperate zones
climate	marine climate	transpiration
conduction	mesosphere	tropics
convection	nitrogen	troposphere

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Air is a mixture of gases.
2. Air is dissolved in all the waters of the earth.
3. Air pressure increases with altitude.
4. The atmosphere contains several layers which are separated distinctly.
5. Radioactive particles and "shooting stars" are matter from space which could be dangerous to life on earth.
6. Carbon dioxide composes a very large and unimportant part of the atmosphere.
7. Summer in Argentina comes between December and February.
8. The equator has two periods of summer when the sun shines directly on it.
9. Temperate climates of the earth lie between $23\frac{1}{2}°$ and $66\frac{1}{2}°$ north and south latitudes.
10. Climates and weather depend upon the circulation of the atmosphere.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Much energy from the sun which becomes heat for the planet earth is first changed into (*ozone, ultraviolet rays, infrared rays*).

2. Plants help supply animals with (*carbon dioxide, oxygen, nitrogen*).
3. Animals add (*carbon dioxide, oxygen, nitrogen*) to the earth's atmosphere.
4. The atmosphere contains at least (*5, 7, 9*) layers.
5. The troposphere is the layer which contains (*½, ⅔, ¾*) of the earth's atmosphere.
6. Molecules of oxygen in the mesosphere contain (*2, 3, 4*) atoms.
7. The most plentiful gas in the air is (*carbon dioxide, oxygen, nitrogen*).
8. The most important heating process for the atmosphere is (*radiation, conduction, convection*).
9. The axis of the earth is tilted from the vertical at an angle of (*23½°, 33⅓°, 66⅔°*).
10. The longest period of daylight at the equator is (*8, 12, 16*) hours.

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The pressure of the atmosphere at sea level is __?__.
2. You live in the layer of air called the __?__.
3. The layer of air called the __?__ is important to radio reception.
4. The layer of air which protects you from harmful rays and fragments from outer space is the __?__.
5. Jet planes ordinarily fly just below the __?__.
6. The form of atmospheric gas which absorbs ultraviolet radiation is __?__.
7. The earth's atmosphere is held in place near the earth by __?__.
8. The thermal blanket which regulates the heat of the earth is mainly composed of __?__ and __?__.
9. The major climatic regions of the world are __?__, __?__, and __?__.
10. The latitude which marks the southern limit of the sun's direct rays is called the __?__.

D. How and Why

1. How much air is pressing on the cover of your closed book? (Use air pressure at sea level.)
2. Why is man's greatest interest concentrated on the layer of the atmosphere known as the troposphere?
3. Why is the zone beyond the mesosphere called the ionosphere?
4. Why do shifts in the ionosphere affect radio reception?
5. Why must space vehicles have protective heat shields?
6. Why are there few or no clouds in the stratosphere?
7. In what way do pressurized cabins and pressurized suits protect humans in the upper atmosphere?
8. The lower layer of the atmosphere plus that part of the crust to the depth of the oceans is often called the *biosphere.* Suggest some reasons for this term.
9. Why is nitrogen sometimes called the "element which doesn't do anything?" Is this idea a fact?
10. How is the process of heat radiation related to the formation of dew or frost?

INVESTIGATIONS

1. Refer to a magazine, such as *Holiday,* which gives average temperatures for cities in different parts of the world. Compare average temperatures for Honolulu, Buenos Aires, Athens, Mexico City, Toronto, Moscow, Juneau, and Phoenix. Indicate in which climatic region each city is located. From information in a geography book or an atlas, decide whether any other factors, such as marine, mountain, mid-continent, or desert location, or low altitude, have any influence on the temperatures. In what season is each city at the time you made the chart?
2. Refer to the daily paper and keep a daily weather chart on six cities for one week. Choose one city in a desert climate, one city in the extreme north, one city in a mountain region, one city on either the west coast or the east coast, and one city in the middle of the continent. This chart should include daily high temperature and low temperature. Compare temperatures for daily variance and day-to-night variance.

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Winds and Weather

Air is constantly in motion. Horizontal movements of air are called winds; vertical movements are called currents. Winds and currents distribute the sun's radiant energy which has been transformed into heat by absorption at the earth's surface. They also determine the circulation pattern of the atmosphere. Winds and currents carry air from regions of high pressure and great density to regions of low pressure and less density. Air is relatively cold in areas of high pressure and relatively warm in areas of low pressure.

Water vapor weighs less than an equal volume of air. Consequently, dry air is more dense than moist air, in which molecules of oxygen, nitrogen, and other gases are displaced by water vapor. Elevation also affects density. But, in general, temperature accounts for most differences in density.

10:1 *Air Circulation*

The equator is a zone of high temperature and low pressure.

Between latitudes $23\frac{1}{2}°$ north and south, the earth receives more radiant energy than in any other region. Consequently,

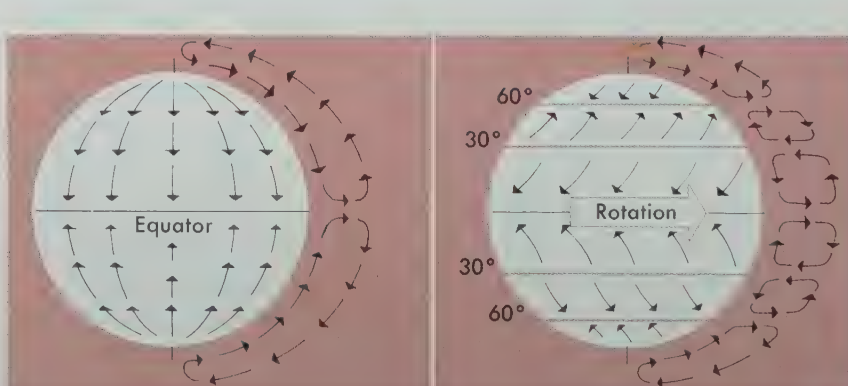


Figure 10-1. Major north-south convection currents in earth's atmosphere are broken into eddies by the earth's rotation, forming the wind pattern of the globe.

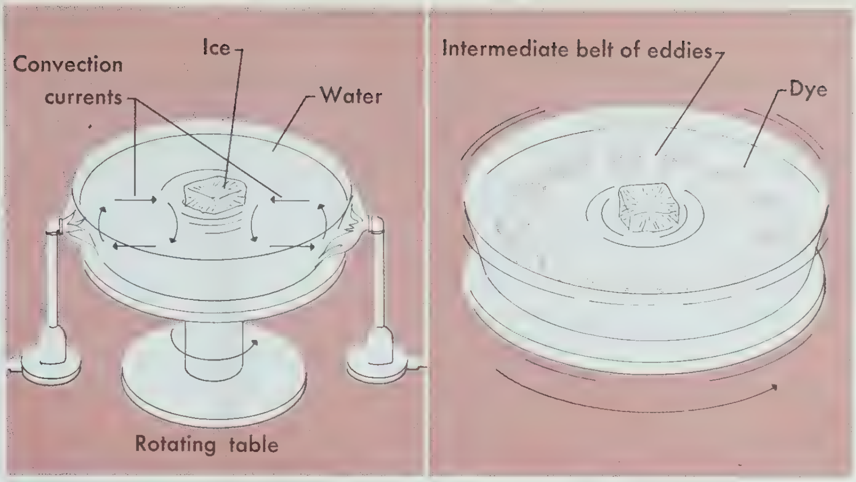


Figure 10-2. Rotation of the pan illustrates a distribution of energy resembling the earth's major wind pattern.

air at the equator is warmer than in adjacent latitudes. Currents of warm air rise at the equator. Cold surface air flows toward the equator to replace the rising currents of warm air. Warm air rises and eventually flows poleward to take the place of the polar air that flows toward the equator. Circulation of the atmosphere tends to distribute heat from the equatorial region to the rest of the earth. If the earth did not rotate on its axis, the atmosphere would resemble a giant hot air heating system in which currents move north and south.

Winds move from high to low pressure areas. High pressure is associated with cold air, low pressure with warm air.

Warm air rises because it is less dense than cold air.

Because the earth rotates and because the earth has an uneven amount of land and water areas, atmospheric circulation is extremely complicated. Victor P. Starr, an American meteorologist, developed a model of heat and cold exchange in an attempt to understand the major wind systems. Starr's model consisted of a shallow pan of water which contained ice at the center. By heating the outer rim of the pan, Starr set up a convection current. Warm water flowed across the surface toward the cold center. Cold water from the center flowed across the bottom and rose at the outer rim. After the simple convection pattern was established, Starr started the pan rotating. During the experiment, Starr discovered that the faster the pan rotated, the more the water broke up into eddies. He added dye to the water so he could trace movements of the currents. After the dye had circulated, the eddies looked like the lines on a weather map. Eddies moved toward an intermediate belt from both the outer warm rim and the cold center. The results of Starr's experiment suggest that the major wind patterns on earth are controlled by the unequal heating of the earth coupled with the earth's rotation.

As applied to air masses, cold and warm are relative terms.

Eddies are circular currents.

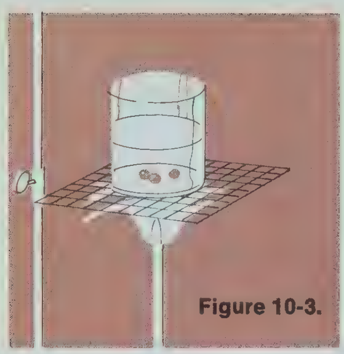


Figure 10-3.

EXPERIMENT. Put some cinnamon drops in the bottom of a beaker and fill the beaker half full with water. Heat the beaker over a Bunsen burner. What happens to the color from the candy as the water nears the boiling point? In your notebook, draw the circulation pattern of the water. Which kind of heating that also occurs in the air do you observe in the water?

The apparent force that causes moving bodies to be deflected by the earth's rotation is called the **Coriolis** (kohr ee oh'lis) **force**. Although the convective circulation is in a north-south direction, all winds are deflected by the Coriolis force. Because the earth turns toward the east, every body moving across its surface has an eastward component of motion. The Coriolis force is caused by differences in the velocity of rotation. At the equator, the velocity of rotation is at its maximum (1000 mi/hr); at the poles the velocity of rotation is at its minimum (0 mi/hr). A particle of air that moves directly south in the northern hemisphere appears to be deflected toward the right. A particle of air that moves directly north in the southern hemisphere is deflected toward the left. These apparent changes in direction of the particle of air are due to inertia of the particle and to motion of the earth below the particle.

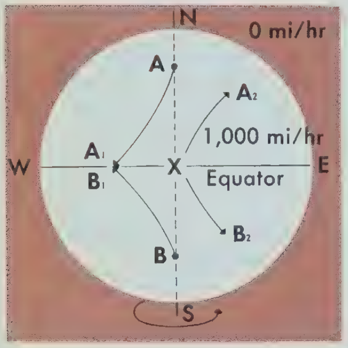


Figure 10-4. As an air particle travels from *A* toward *X*, *X* is carried eastward and the particle arrives at A_1. An air particle moving from *X* toward the north pole would arrive at A_2.

Consider what happens to a particle of air moving on a north-south line from the north pole to the equator. The point on the equator moves eastward faster than the points lying farther north. Consequently, when the air particle reaches the equator, the point toward which it was moving has already moved some distance eastward. Although the air particle has actually been traveling directly southward, its apparent direction of travel appears to be from northeast to southwest.

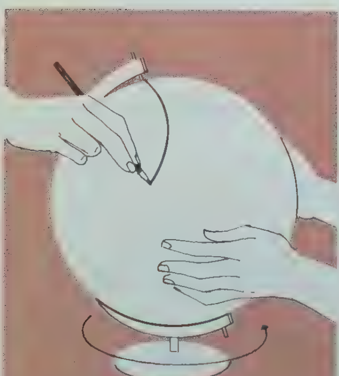


Figure 10-5.

EXPERIMENT. On a classroom world globe, determine how a north-south line is affected by the turning of the earth beneath it. With a grease pencil, begin marking lightly on the globe at the north pole as another student turns the globe from left to right. Hold the grease pencil erect, maintain a steady pressure, and move the pencil directly toward the equator. Attempt to make a straight line from the north pole to the equator while the globe turns. What is the direction of the line? What determines the direction of the line? Repeat the experiment and move the grease pencil from the south pole toward the equator. Are the lines the same in both hemispheres? How do they differ? Which lines represent surface wind movements?

10:2 Major Wind Systems

Rising currents of warm air produce a quiet, almost windless zone on the surface at the equator. This zone of quiet is known as the *doldrums* (dohl'drums). In the days of sailing ships, vessels often were stranded in the doldrums for many days. On either side of the doldrums, winds blow toward the equator. These winds bring cool air to replace the warm air that rises over the equator. (Figure 10–6.)

The **doldrums** is a windless zone at the equator where air seems to be motionless because it is rising.

Trade wind belts extend from the doldrums to about 30° latitude both north and south of the equator. In the northern hemisphere, the trade winds blow from northeast to southwest. In the southern hemisphere, trade winds blow from southeast to northwest. Trade winds are also known as the **easterlies.** Notice that winds are named for the direction *from* which they blow. In the zone of the easterlies, winds are deflected toward the west, because the air flows from a zone in which the rotational velocity is less than it is at the equator.

Winds blowing toward the equator are deflected toward the west, and are called easterlies.

The zone of the **westerlies** lies between 30° and 60° latitude. Air currents descend to the earth's surface at 30° latitude. Part of the air turns southward as the trade winds; part of the

Winds blowing toward the poles are deflected toward the east, and are called westerlies.

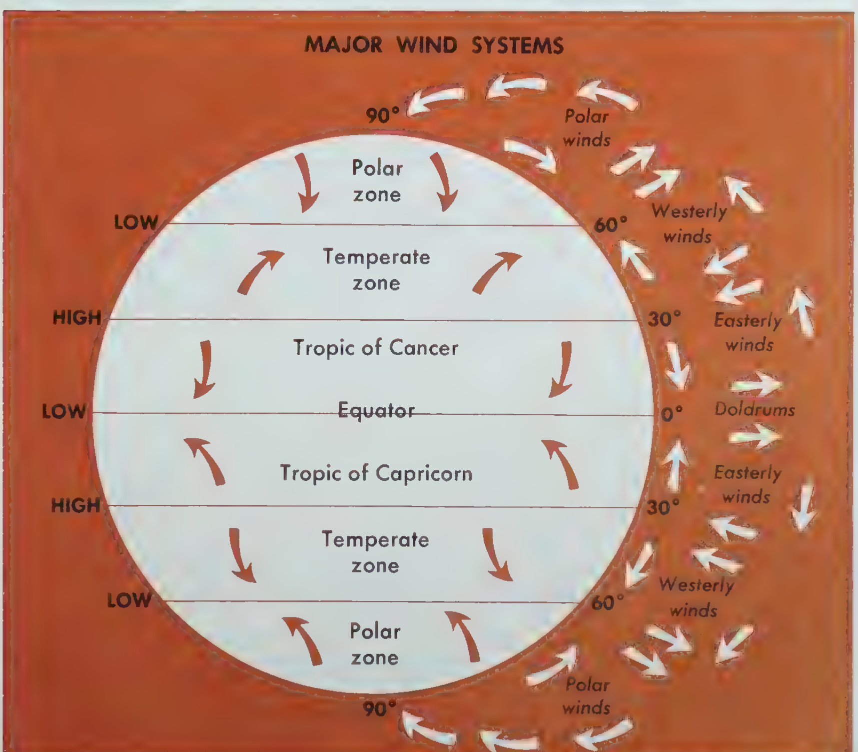


Figure 10-6. Surface winds blow from regions of high-density descending currents toward regions of low-density ascending currents.

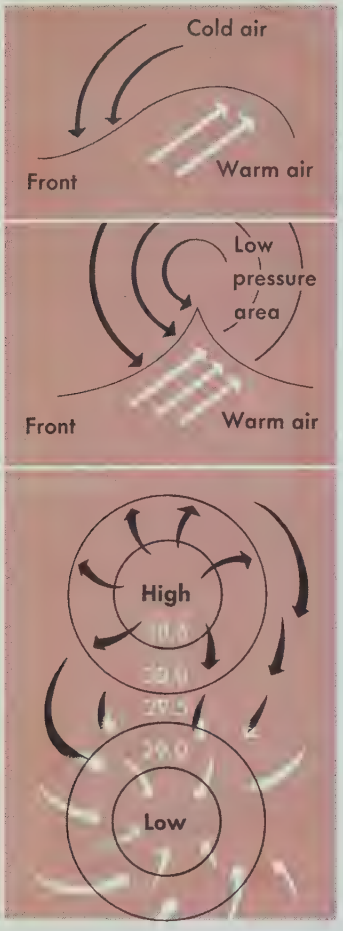


Figure 10-7. Cold air blows outward from the center of an anticyclone toward the low-pressure cyclone center, often causing warm air to rise above the cold air.

air flows northward as the westerlies. Westerly winds blow from a zone in which the velocity of rotation is greater than the velocity of the zone toward which the air is flowing. Winds are deflected toward the east. In the northern hemisphere, westerly winds blow from southwest to northeast. In the southern hemisphere, westerly winds blow from northwest to southeast.

Weather in the zone of the westerlies depends on winds and air masses from both the tropics and the polar regions.

The zone of the westerly winds is noted for its changeable weather. Individual eddies, like those produced in Dr. Starr's experiment, form in the middle latitudes. Eddies are revolving masses of air called *cyclones* (sie'klohns) and *anticyclones*. Cyclones are local areas of low pressure and warm air; anticyclones are local areas of high pressure and cold air. Cyclones and anticyclones tend to follow one another across the continents from west to east. They travel with the major wind system. Locally, winds blow from the high pressure center of an anticyclone toward the low pressure center of a cyclone. Day-to-day weather changes result from the mingling of cold and warm air brought into contact by the winds of the cyclones and anticyclones. The masses of cold air drift into the zone of the westerlies from the polar regions. Masses of warm air reach the westerly zone from the vicinity of the tropics. Storms and turbulence result from the mingling of air masses in the zone of the westerlies.

Clouds, rain, or snow may occur when highs and lows overtake one another.

Polar wind zones lie between 60° latitude and the poles. Upper air currents flowing poleward from the equator are cooled during their journey. As the currents approach the poles, they are cold, dry, and dense. These air currents descend to the earth's surface in the vicinity of the poles. From the poles, the air flows toward warmer latitudes. Polar winds are turned westward by the Coriolis force as they move into regions of increasing rotational velocity. Polar zones are relatively small compared to the area of the westerlies. But polar winds contribute large amounts of energy to the zone of the westerlies.

At about 60° latitude, the cold polar air at the surface displaces the warmer air of the westerly zone and forces the warm air to rise. Eventually, this rising current of air joins the other poleward-moving currents from the equator. Radiant energy from the sun keeps the atmosphere in constant motion and, thus, causes daily changes in wind, moisture, and temperature ranges.

Atmospheric turbulence is most noticeable in the troposphere, the layer of air closest to the earth. Air is constantly rising, descending, and moving horizontally. Wind velocities

often are measured in several miles per hour at the earth's surface, but both the easterlies and westerlies reach their maximum velocities at some distance above the earth. Easterlies have their greatest velocity at about 1 mi or 2 mi above the earth's surface; westerlies have their maximum velocity at an altitude of about 7 mi.

Polar winds that are deflected toward the west are called polar easterlies.

Just above all this turbulence is a zone of relative quiet called the *tropopause* (troh′pa pawz). Jet planes often escape the clouds and winds of the troposphere by flying in the tropopause. However, near the upper boundary of the tropopause, where it merges with the stratosphere, air movement begins again. Here a stream of air, called the *jet stream*, flows from west to east at high velocities. In the jet stream, winds may reach a speed of 35 mi/hr in the summer and 90 mi/hr in winter. Occasionally, however, velocities of 200 mi/hr are reached. The jet stream may be 300 mi wide and 1 mi or 2 mi deep.

The **tropopause** is a zone of relative quiet between the troposphere and stratosphere.

Jet streams are strong winds blowing from west to east at the top of the tropopause.

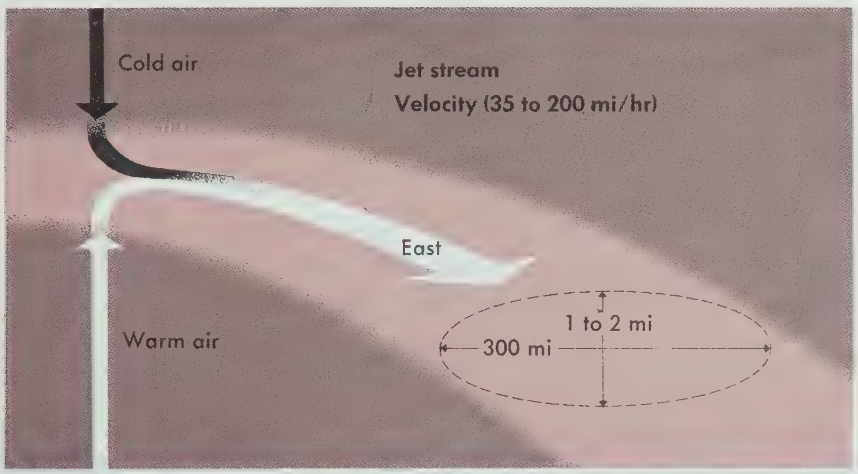


Figure 10-8. The jet stream forms when rising warm air currents meet descending cold air currents at the lower boundary of the stratosphere.

Jet pilots often use the jet stream to increase their speed when they are flying eastward. But they avoid the jet stream when flying westward. The jet stream is not in a fixed position; it may wander north or south, or upward and downward. The force of the jet stream diminishes with time, and winds wobble from side to side and up and down until their energy is spent. Eventually, the jet stream may settle downward into the path of the wind system of the troposphere. The jet stream sinks toward the earth if warm air slides over the stream. Unusually severe storms occur in the zone of the westerlies when the jet stream interferes with the surface wind system.

10:3 Weather

Weather refers to temperature, amount of moisture, air pressure, wind direction, and wind velocity.

Weather includes the day-to-day changes in wind, temperature, humidity, and pressure. Weather changes little from day to day or from winter to summer in the tropics. But in the zone of the westerlies, weather is indeed changeable.

Surface conditions determine the character of an air mass that remains stationary for several days above the area.

Masses of air that stay in place for some length of time acquire characteristics of heat or cold, humidity or dryness, from the surface of the earth over which the air stands. Masses of air that originate over the ocean tend to be moist. If the mass originates over the ocean in the tropics, the mass is both warm and moist. Large masses of cold, dry air originate in the temperate zone in winter, and near the Arctic Circle at any time of year. Small masses of hot, dry air may form over deserts. Warm, moist air masses may develop over large inland lakes. Air masses are carried from regions of high pressure to regions of low pressure by major wind movements. The forward edge of a cold air mass is known as a *cold front*; the forward edge of a warm air mass is called a *warm front*. Weather forecasters predict local weather changes on the basis of the movement of cold fronts and warm fronts.

Forward edges of cold and warm masses are known as cold fronts and warm fronts, respectively.

In North America cold air masses tend to move toward the southeast; warm air masses tend to move toward the northeast.

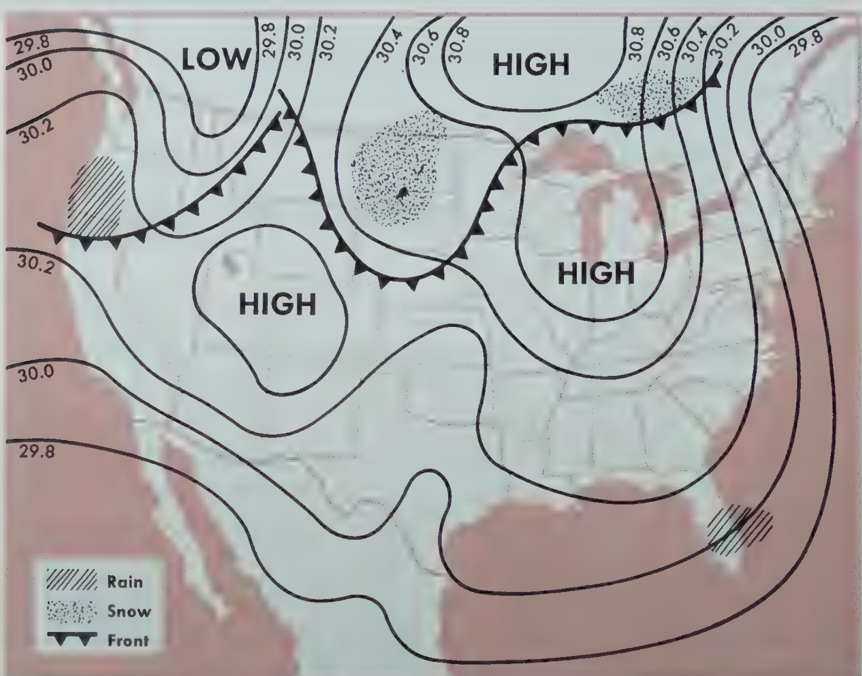


Figure 10-9. Local weather conditions are determined by the passage of high pressure and low pressure areas which follow each other in the zone of the westerlies.

When cold fronts collide with warm fronts, thunderstorms are common. Cold air pushes under the warm air and causes the warm air to rise rapidly. As the warm air rises, it cools, and its moisture condenses. If a warm front follows a cold front and overtakes it, rain occurs. In this case, however, rains are usually gentle and last for a longer time. (Figure 10–9.)

EXPERIMENT. Make a weather vane. Cut a triangular piece of sheet aluminum for a pointer and a square piece of aluminum for a tail. Attach these pieces to the opposite ends of a piece of wood 1 in. wide and 1 in. thick. Drill a ¼ in. hole in the stick at its balance point. Oil the hole and with a long screw mount the vane on a piece of wood 2 in. thick and 4 in. wide. You can improve the rotation of the vane by placing a well-oiled skate bearing or a washer between the wood surfaces. Set the vane in the wind and let it adjust to the wind direction. Use a compass to determine the direction of the wind. For one week, record the wind direction at the same hour. Check your readings with the local weather report. If the readings differ, does it mean your data are wrong?

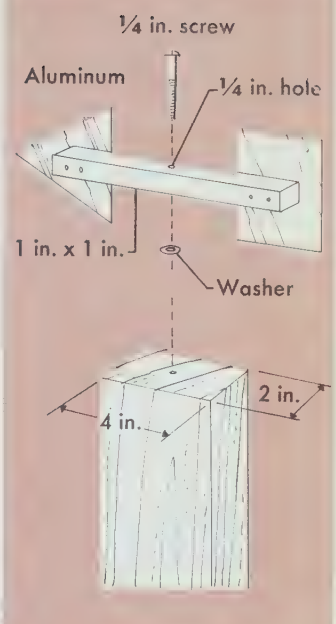


Figure 10-10.

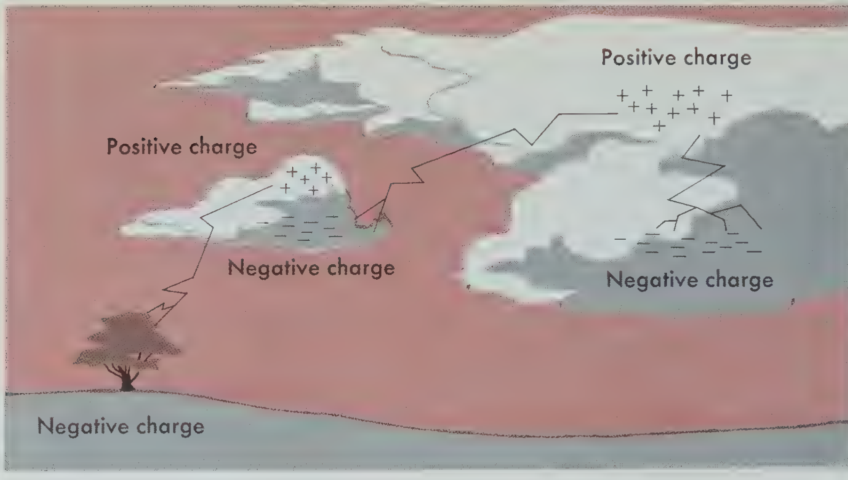
Thunderstorms occur when warm (at least 0°C or 32°F) air masses or fronts are forced vertically upward. The most common type of thunderstorm occurs in temperate latitudes during the warm summer season. Convection currents cause most thunderstorms. Warm air starts to rise when unequal heating of the earth's surface causes a local disturbance of the near-surface air. Upward momentum carries the rising air to higher and colder heights. Eventually, the current of air loses momentum, spills over, and starts to fall. Cold temperatures may cause the water vapor to condense and fall as rain, hail, sleet, or snow.

If warm fronts overtake cold air masses, slow gentle rainfall results.

In 1752, Benjamin Franklin proved by his famous kite experiment that a thundercloud generates electricity. The process by which the electricity is generated is not entirely understood, but it is known that positive and negative electrical charges are generated within the cloud. Negative charges usually collect on the lower surface of the cloud. Positive charges usually accumulate in the upper parts of the cloud. Electrical charges build up in such large quantities in clouds that the electricity may suddenly discharge by leaping from cloud to cloud, or from cloud to earth. Such sudden electrical discharges create bright flashes of light called *lightning*. Lightning strokes cause sudden heating of the air along their paths. Sudden heating expands

Lightning is an electrical discharge in the atmosphere.

Figure 10-11. The presence of both positive and negative electrical charges within clouds may cause a sudden discharge of electricity, or lightning.



Thunder is the noise that accompanies abrupt pressure waves formed when lightning heats the air rapidly.

the air so rapidly that abrupt pressure waves are formed. Explosions of any kind create similar waves, accompanied by loud noise. *Thunder* is the loud noise created by pressure waves formed by strokes of lightning. Thunder may be heard long after the flash of lightning has disappeared. The noise continues partly because sound waves travel more slowly than light waves, and partly because multiple lightning strokes produce multiple pressure waves. Rumbling and various other sounds associated with thunder are the result of differences in the distances traveled by lightning strokes combined with noise reflected from both clouds and the earth.

Westinghouse Electric Corporation

Figure 10-12. When earth's negative electrical charges react with a cloud's positive charges, lightning may strike the earth.

Lightning strokes may carry large quantities of electric current which can be dangerous to life and property. Destructive forces due to lightning are of several different types. In addition to the heating effect, there are also explosive, crushing, and electrical effects. Magnetic and chemical effects are also associated with lightning.

Use of lightning rods to protect buildings from lightning damage was originated by Benjamin Franklin. Pointed metal rods are placed at intervals of 25 ft around the tops of buildings. The lightning rods attract the lightning stroke before it can reach the building. The electrical charge at the pointed ends of the rods is the same as that of the earth with which they are connected. Attraction of opposite charges between thunder clouds and the pointed rods provides a route of low resistance for the cloud charges to follow to the earth without entering the building. The electrical charge is carried from the rods by copper conductors to grounded metal plates or wires in the earth, where it becomes harmless. In properly protected buildings, human life is in little danger from lightning.

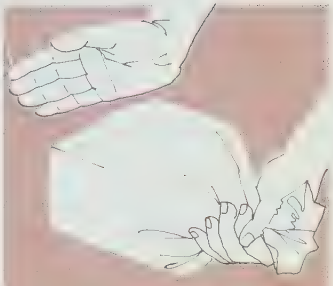


Figure 10-13.

ACTIVITY. Blow into a paper bag until it appears to be filled. Break the bag quickly. Explain what happens.

Rainbows are often associated with rainfall. If the sun appears during the rainfall, an arc of color may spread across the sky. Water droplets suspended in the air act as prisms and separate the sunlight into all its colors. The colors, known as the **spectrum** (spek′trum), always occur in the same order: violet, indigo, blue, green, yellow, orange, and red. The center of a rainbow is always 180° from the sun. When the sun is setting, the rainbow is fairly high in the eastern sky. If the sun is high in the sky, the rainbow may not be visible above the horizon.

Rainbows occur when drops of water in the atmosphere separate the sunlight into its spectrum.

Tornadoes are violent, destructive storms. Tornadoes form when a mass of warm air becomes trapped between two layers of cold air. If an opening is present in the upper layer of cold air, the warm air rushes upward in a spiral pattern. The center of the spiral is an area of low pressure toward which the surrounding air rushes. Violent winds associated with a tornado result from the vast difference between the pressure at the center of the tornado and the pressure in the surrounding region. When the air spirals upward suddenly, the pressure drops rapidly and causes the great difference in pressures. The center of the tornado is most dangerous because pressures there are

Tornadoes are whirling storm centers of extremely low air pressure.

much lower than the pressures of closed buildings. Buildings located in the center of an updraft may burst outward. Opening windows and doors helps to equalize the pressure within and without and lessens the effect of the tornado. The path of a tornado is usually only about $\frac{1}{8}$ mi to $\frac{1}{4}$ mi wide.

Official U.S. Navy Photo

Figure 10-14. Here a tornado is forming as warm air spirals upward through a break in the upper cool layer. The greatest number of tornadoes occurs in the United States.

Hurricanes are large masses of low pressure with violent winds blowing toward the center, or **eye.**

Hurricanes are violent storms of lesser wind velocity, but they affect a greater area than tornadoes. Low pressure areas form over water in the zone of the trade winds. These masses of warm moist air begin to move, carried forward by the major wind system. As the masses move, they rotate. Hurricane winds blow inward toward the low-pressure center, or the "eye," with velocities as high as 150 mi/hr. At the center of the hurricane, the eye is a zone of relative quiet because air currents are rising. The *squall line*, the area where cold and warm fronts meet, may cover hundreds of miles and persist for several days. Hurricanes often bring violent weather to the Gulf of Mexico and the eastern half of the United States during the early fall.

Hurricanes originate over water in the trade wind belt during the fall season.

Much of the damage associated with hurricanes comes from the waters that pile up along the shore in front of the wind. As a hurricane moves landward, it blocks the return of water to the open ocean. Water spills across the shore zone in great waves. Streams also are affected by the hurricane. Normally,

Official U.S. Navy Photo

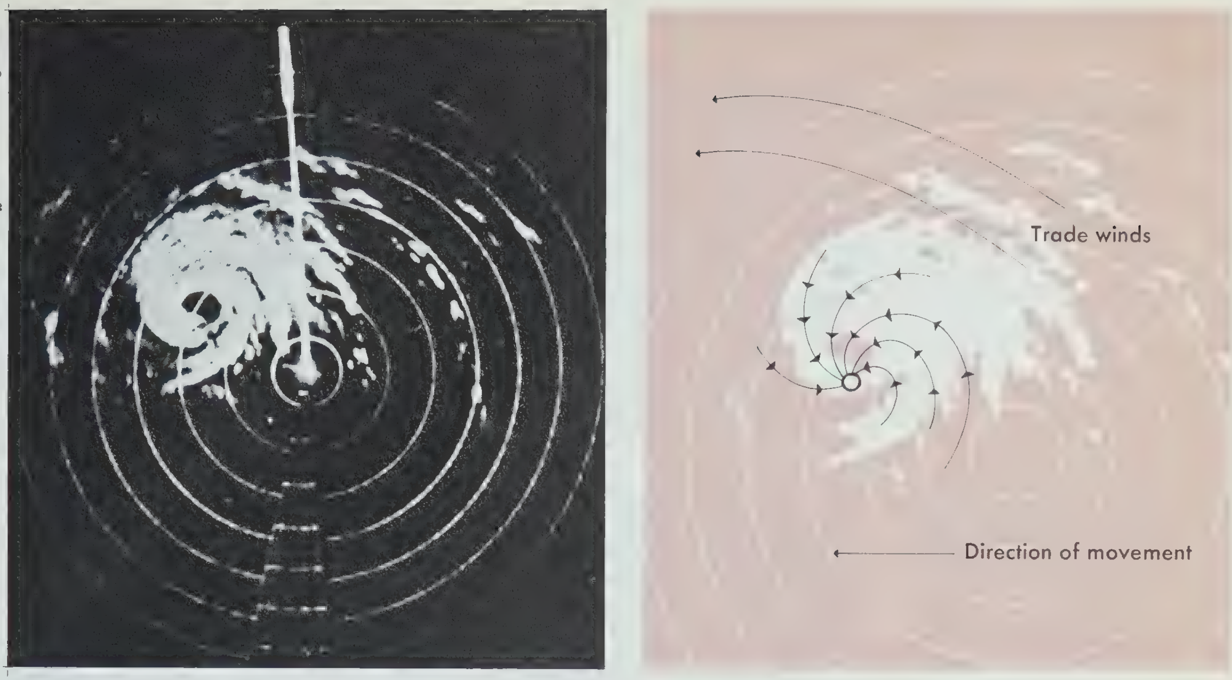


Figure 10-15. Radar shows a spiral of warm air forming into a hurricane in the zone of the Trade Winds. Maintaining its unique spiral form, the hurricane is carried westward by the Trade Winds.

their waters are emptied into the sea. But if the mouth is dammed by high water, a stream may back up, overflow its banks, and flood the surrounding land.

Convective storms are storms typical of the tropics. Air flows toward the equator from adjacent latitudes. This air is cooler than air at the equator, although the air is not cold. At the equator, the trade winds join the rising column of air. As the air rises, it is cooled, and eventually its moisture condenses and falls as rain. Rainfall is a daily occurrence in the equatorial zone wherever moisture is available. Trade winds that blow across the land are dry and have little water vapor, but winds that blow across the ocean supply abundant moisture for the tropical rain forests

Convective storms occur in the doldrums as the rising air is cooled.

Monsoons (mahn soonz′) are seasonal winds. They are well known for their effect on the seasons in India, but monsoon winds occur in other places as well. Monsoons blow from land to sea when high pressure zones develop over the land. Monsoons blow from sea to land when high pressure zones develop over the sea. From June to September, the land area of India is warmer than the Indian Ocean, which lies south of the continent. The direct rays of the sun fall on India as the sun moves northward during the summer, and the land heats faster than the water. Then winds blow from the cool Indian Ocean toward

Monsoons are seasonal winds blowing from land to sea during a part of the year and from sea to land during the rest of the year.

the warm land. When the winds reach northern India, they rise to cross the mountains. Air cools as it rises, and its moisture condenses and falls on the lands south of the mountains. During the winter, the direct rays of the sun strike the Indian Ocean instead of the continent. The land mass of India becomes colder than the adjacent ocean, and winds then blow toward the sea. Winter winds are evaporating winds because they become warmer as they travel southward, and they are able to hold more and more moisture. Because of the monsoon winds, India has alternating wet and dry seasons.

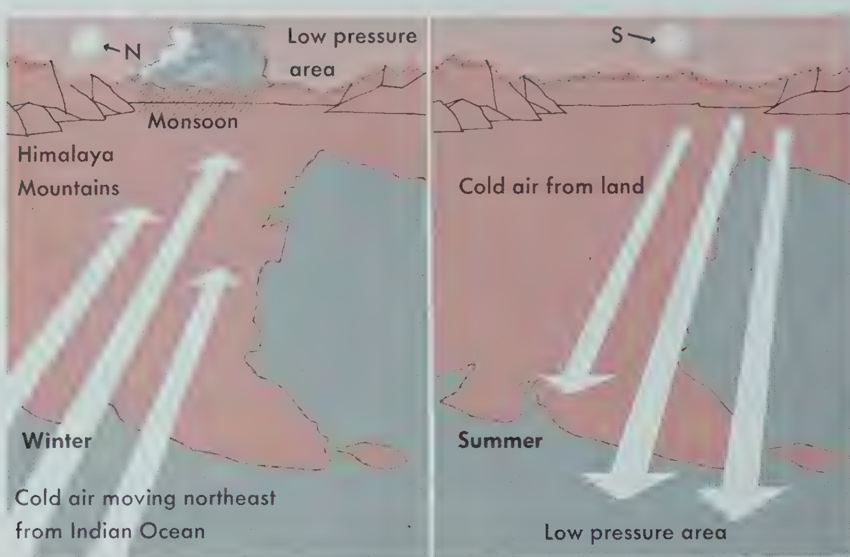


Figure 10-16. As the summer sun heats the Asian continent, moist winds blow landward and cause rain. Dry winds blow seaward as the sun's direct rays move southward and heat the Indian Ocean.

10:4 *Clouds*

Rain, hail, and snow occur if enough moisture condenses and droplets become large enough to overcome the buoyancy of air.

Clouds are condensed moisture suspended in air molecules. Moisture condenses around dust particles or salt crystals when the air is cooled below its dew point or saturation point. (Section 9:5.) The *dew point* is the temperature at which air is holding all the water vapor possible; that is, the air is 100 percent saturated with moisture. Some clouds collect enough moisture and droplets become large enough to overcome the buoyancy of air. Then the moisture falls as rain. Many clouds do not bring rain. Some clouds even disappear during the day as the temperature rises and the air is able to hold more moisture. Cooling of the atmosphere results from radiation of heat, from mixing of cold and warm fronts, and from rising air currents..

Cumulus (keu′mya lus) clouds are the white fluffy masses commonly formed on summer afternoons. Cumulus clouds seldom collect enough moisture to be rain clouds. *Cirrus* (sir′us) clouds are wispy, high, thin clouds formed in the upper part of the troposphere. Cirrus clouds consist of ice crystals, instead of water droplets, because moisture condenses where temperatures are below freezing. *Stratus* (straet′us) clouds are low, widespread layers of condensation. Commonly, stratus clouds bring rain because cold and warm layers of air are being mixed. Slow, gentle, long-lasting rainfall is often associated with stratus clouds. *Cumulonimbus* (keu mya loh nim′bus) clouds are masses, often called thunderheads, that rise to great heights and commonly bring thunderstorms with them. Cumulonimbus clouds begin as cumulus forms, but as more and more moisture collects, their shape changes. Cumulonimbus clouds are black and large, and commonly cover much of the sky.

Figure 10-17. a. Cumulus clouds form as warm air rises, cools, and condenses; b. layers of dense stratus clouds often bring rain; c. high cirrus clouds contain ice crystals; d. cumulonimbus clouds often bring lightning and thunderstorms.

a. b.

USDA Photo *Official U.S. Air Force Photo*

c. d.

Official U.S. Air Force Photo *Official U.S. Air Force Photo*

Clouds affect weather by screening the sun's rays. Daytime temperatures are usually lower when clouds cover the sky. On the other hand, a cloud cover prevents loss of heat during the night. Consequently, day and night temperatures tend to be less variable under cloudy skies than under clear skies.

Rain, hail, sleet, and snow are associated with storm clouds. *Snow* forms if moisture condenses in air in which the temperature is below freezing. Cirrus clouds are so high that they do not produce snow. Other types of clouds nearer the earth may bring snow during the winter. *Hail* forms if rain falls through a layer of cold air where the temperature is below freezing. Ice forms from the drops of water, and hail may occur even on warm summer days. *Sleet* is smaller particles of ice formed in much the same way as hail. However, sleet occurs only in winter because in summer the particles melt and form raindrops as they pass through warm air.

10:5 *Local Climates*

Local climates depend on the temperatures, rainfall, and wind directions averaged for at least a 10-year period.

Within the major climatic regions of the earth, there are **local climates** which are determined by local weather conditions. Temperature, rainfall, and wind conditions of at least a 10-year period are averaged to determine the classification. In general, weather of continental areas is controlled mostly by the wind belts in which they lie. However, certain types of local climates are influenced by particular conditions.

Deserts are regions in which annual rainfall is less than 10 in. Little water vapor is present to prevent loss of heat at night; no cloud cover screens the sun's rays during the day. Deserts heat quickly in the day and cool quickly at night. The temperature range between day and night may be as much as 40°F or 50°F (4.4°C to 10°C).

Leeward sides are sides protected from the wind. **Windward** sides are sides which face the direction from which the wind blows.

The Gobi Desert and Sahara Desert occur where winds blow across land with no available moisture.

Deserts occur in almost all latitudes. They are found on the leeward sides of mountains that lie across wind directions. Deserts also occur in the interior of continents. Winds that travel long distances across dry land tend to lose their moisture early, and have little opportunity to absorb more moisture. Consequently, continental interiors are often deserts. The Gobi (goh′ bee) Desert of China is a good example of an interior continental desert. The Sahara Desert of Africa is another region where little moisture is brought to the land by winds. In fact, winds that blow across the Sahara Desert are evaporating winds. The 30° north latitude line lies about midway across the

Sahara. The trade winds become warmer and warmer as they approach the equator and are capable of absorbing more and more moisture as they blow southward. But because the winds travel across land areas, little moisture is available to them. Such winds are evaporating winds that take away moisture, rather than bring rain.

Mountains influence the amount of rainfall in their vicinity. They may cause desert conditions on their leeward slopes if the winds cross the mountains. Rain forests may occur on the windward slopes where winds lose moisture before they cross the mountains.

Rain forests may occur on windward slopes of the mountains that lie in the path of the major wind belts.

In California, the westerly winds rise to cross the Coast Ranges and the Sierra Nevada. As the air rises, it cools, and its moisture condenses. Moisture then falls as rain on the western slopes of the mountains. In northern California and Oregon, lush vegetation results from the abundant rainfall on the windward side of the mountains. On the leeward slopes of the mountains, winds are dry, and desert or semi-desert conditions are common.

Death Valley is a desert lying on the leeward side of the California mountains. Winds descend the mountain slopes into the valley. Gradually, the air becomes warmer and able to hold more and more moisture. However, little water is present, and desert conditions result. An evaporating wind that blows across the mountains in Wyoming is so dry that it often absorbs the spring snows without melting them. The wind is named the Chinook (shi nuhk′) wind for the Indians of the area.

Death Valley lies on the leeward slope of the California mountains where winds are dry because they have lost their moisture in crossing the mountain slopes.

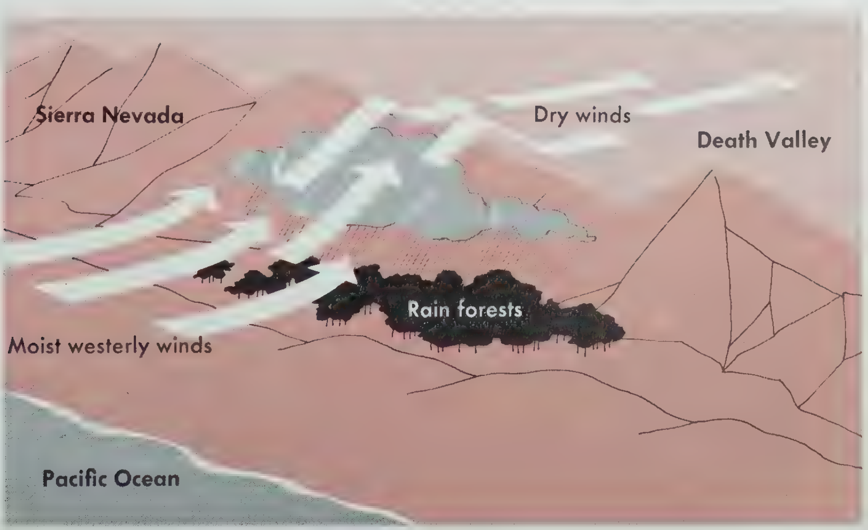


Figure 10-18. Winds lose their moisture as they rise to cross the Sierra Nevada; they become evaporating winds as they descend into Death Valley.

Marine climates are typical of regions lying near the ocean. Moisture is abundant in the atmosphere, and rain is common. Temperature variations from night to day are commonly only 2°F or 3°F. This is a great contrast to the 40°F to 50°F variation of the desert regions.

Oceans tend to equalize the day and night temperature because they absorb and radiate heat less quickly than the land.

Bodies of water absorb and radiate heat more slowly than adjacent land areas. During the day, the land heats and the water remains cool. Winds, called *sea breezes*, then blow from the cool water to the warm land. During the night, heat from the land is radiated, and the land becomes colder than the body of water. A high pressure area develops on the land and winds, called *land breezes*, blow toward the warm, low pressure zone over the water. Marine climates affect all shore zones near large bodies of water.

MAIN IDEAS

1. Radiant energy from the sun is transformed into heat by absorption at the earth's surface and the heat is then distributed by the atmosphere.
2. Rotation of the earth, distribution of land and water areas, and the exchange of heat between warm and cold areas causes the circulation patterns of the atmosphere.
3. The entire envelope of air surrounding the earth turns eastward as the earth rotates. However, segments of air within the troposphere move upward, downward, or horizontally in response to variations in air pressure caused by differences in temperature.
4. Wind belts are named for the direction *from* which they blow. Easterlies, or the trade winds, blow from 30° latitude toward the equator; westerlies blow from 30° latitude toward 60° latitude; polar winds blow from the poles toward 60° latitude. Winds blowing toward the equator are deflected toward the west; winds blowing toward the poles are deflected toward the east.
5. Cyclones and anticyclones, common in the zone of the westerlies, are local areas of low and high pressure, respectively. Cyclones and anticyclones follow each other across the continents, moving from west to east. Local winds blow toward the center of the cyclone and away from the center of the anticyclone.

6. The tropopause is a zone of quiet air at the upper level of the troposphere. The jet stream is a high velocity wind located at the boundary between the tropopause and the stratosphere.
7. The zone of the westerlies has changeable weather because warm air masses from the tropics and cold air masses from the polar regions come into contact.
8. Tornadoes are violent storms formed occasionally in the zone of the westerlies. Hurricanes are violent storms formed usually in the fall season in the zone of the trade winds. Both hurricanes and tornadoes result from the presence of low pressure zones toward which winds blow from adjacent high pressure zones. Great differences in pressure are responsible for the violence of the winds.
9. Rainforests occur where rainfall is especially abundant. They are found in the tropics, associated with daily rainfall, and on the windward slopes of mountain barriers, both in the tropics and the zone of the westerlies.
10. Rainfall in deserts is less than 10 in./yr. Deserts occur on the leeward side of mountain barriers and in the interior of continents where winds become warmer and are able to absorb more moisture.
11. Monsoons are seasonal winds in the trade wind belt. Monsoons bring rain when they blow from the ocean toward the land. They are drying winds when they blow from the land toward the ocean. Monsoons in India bring a wet season during the summer, a dry season during the winter.
12. Clouds are condensed moisture. They are less dense than the surrounding air. Many clouds do not produce rain, but eventually droplets in stratus and cumulonimbus clouds may become too large to be supported by the air. Then moisture falls as rain, snow, sleet, or hail.
13. Dew point is the temperature at which air is saturated; that is, it holds all the water vapor possible. Cooling below the dew point causes condensation of excess moisture.
14. Marine climates are relatively constant in temperature during both day and night. Changes from winter to summer temperatures are less than in the interior. Moisture in the atmosphere and slow absorption and radiation from the body of water tend to keep temperatures more even than on the continent.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

anticyclone	doldrums	saturate
Chinook wind	leeward	spectrum
Coriolis force	monsoon	tropopause
cyclone	prism	turbulence

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Circulation of the air is affected by heat from the sun.
2. An upward current of air exists at the poles.
3. Cyclones and anticyclones are typical of the zone of the westerlies.
4. Winds blow toward the center of a high pressure area.
5. Both tornadoes and cyclones are high pressure areas.
6. Warm air masses tend to be less dense than cold air masses.
7. Hurricanes originate in huge low pressure areas of warm moist air.
8. Monsoon winds occur only in India.
9. There is a greater daily range of temperature in desert climates than in marine climates.
10. Thunderstorms frequently are associated with cumulonimbus clouds.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Rotation of the earth creates an apparent deflection of poleward moving winds from (*east to west, west to east, north to south*).
2. Heating of the atmosphere results in (*rising, stationary, descending*) currents.
3. The trade wind belt begins at (*the equator, 30° latitude, 60° latitude*).

4. Westerly winds are associated with the (*tropic, temperate, arctic*) zone.
5. Most warm air masses originate in the (*tropic, temperate, arctic*) zone.
6. The center of a(n) (*tornado, rainbow, anticyclone*) is an area of low pressure.
7. Hurricanes are most common in the zone of the (*westerly, trade, polar*) winds.
8. Convective storms are typical of the (*arctic, tropic, temperate*) zone.
9. India has droughts in (*winter, summer, spring*) due to the influence of the monsoon winds.
10. Along seacoasts, (*morning, afternoon, night*) winds tend to blow from the shore.

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The force that causes moving bodies to be deflected by the rotation of the earth is the __?__ force.
2. The zone near the equator where air is relatively motionless is called the __?__.
3. Winds are named for the direction __?__ which they blow.
4. Westerly winds blow between latitudes of __?__ and __?__.
5. The jet stream of the tropopause blows from __?__ to __?__.
6. Tornadoes are most common in the __?__ wind belt.
7. Dry winds that evaporate snow without melting are called __?__ winds.
8. Mountains lying in the path of winds may cause heavy rainfall on the __?__ side and arid conditions on the __?__ side of the mountains.
9. Two deserts located in continental interiors are the __?__ and the __?__.
10. A rainbow is caused by the separation of light into a band of color by water droplets which act as a(n) __?__.

D. How and Why

1. Why does the rotation of the earth deflect winds moving toward the equator? Would the deflection be apparent if you observed the wind movements from a stationary position in space?
2. Why is a cold air mass usually considered a high pressure area?
3. What is the difference between a hurricane and a tornado?
4. Why are weather patterns of the westerlies more complex than those in the trade wind zone?
5. Why are hurricanes accompanied by heavy rain and water damage?
6. Why do the snows of western Montana and Wyoming often disappear without causing runoff waters?
7. Why can tropical rainforests and desert conditions exist at the same latitude?
8. Why are you relatively safe in a steel frame building during a thunderstorm accompanied by lightning?
9. Why do day and night temperatures in a desert have such a wide range, whereas the temperatures along a coast have less change from day to night?
10. Why is the equator the location of warm air currents?
11. Discuss the reason why air moves from high pressure areas to low pressure areas.
12. Why did the Spanish explorers find it easier to get their sailing vessels to Central and South America than to North America?

INVESTIGATIONS

1. On an outline map of the world, draw and label the wind belts in each hemisphere. Explain why the easterlies are also called the trade winds.
2. Watch the weather report on television or get the information from the newspaper. On an outline map of the United States, point out the cold and warm fronts and the high and low pressure areas. If a storm is progressing across the United States, watch its development. Does it make a steady progress, or does it become stationary? If fog is common in your area, explain its formation.

3. Report on the tornado season in the United States. What part of the country is most affected and at what season of the year? Is anything being done to locate and chart tornadoes? Report on the hurricanes of North America. How are hurricanes studied? Is any effort being made to halt hurricanes or to divert them from populated areas?
4. Place a prism in the sunlight so that the sun's rays are diverted onto a sheet of white paper. Note the rainbow colors. Why is a rainbow arched while the colors lie in straight lines on the paper?

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* Well-illustrated material.

The Hydrosphere

In addition to the lithosphere and atmosphere, the earth contains another sphere of matter called the hydrosphere. The hydrosphere includes all water standing in lakes and swamps, all water flowing on the surface in rivers, all water trapped within the rocks below the surface, and all water contained in the ocean basins. The ocean is a continuous body of salt water that covers two-thirds of the earth's surface. Bays, seas, gulfs, and oceans together constitute one vast expanse of water from which continents emerge like islands.

11:1 *The Hydrologic Cycle*

The **hydrologic cycle** is the continuous movement of moisture from ocean to land and land to ocean.

The **hydrologic** (hie dra lahj'ik) **cycle** is the cycle through which water passes from sea to land, and from land to sea. Water vapor enters the air through the evaporation of water. Water vapor in the air eventually condenses and precipitates as rain, snow, sleet, or hail. Water that falls on land collects in rivers which carry it back to the ocean. The return of water to the ocean may be slowed when water becomes trapped in lakes, swamps, or openings in the rocks. Eventually, however, most water returns to the ocean. Like the atmospheric circulation, the hydrologic cycle receives its energy from the sun. Evaporation could not occur without radiant energy from the sun.

Water returning to the ocean carries material from the land to the sea and, thus, erodes the continents.

Destruction of the land through weathering and erosion accompanies the hydrologic cycle. Materials from land are carried to the ocean and deposited there. In the ocean, many of the materials are solidified into sedimentary rock. Other materials remain in solution in the ocean waters. Between land and sea, the hydrologic cycle produces a never-ending exchange of matter. Both destruction and construction of land forms also accompany the hydrologic cycle.

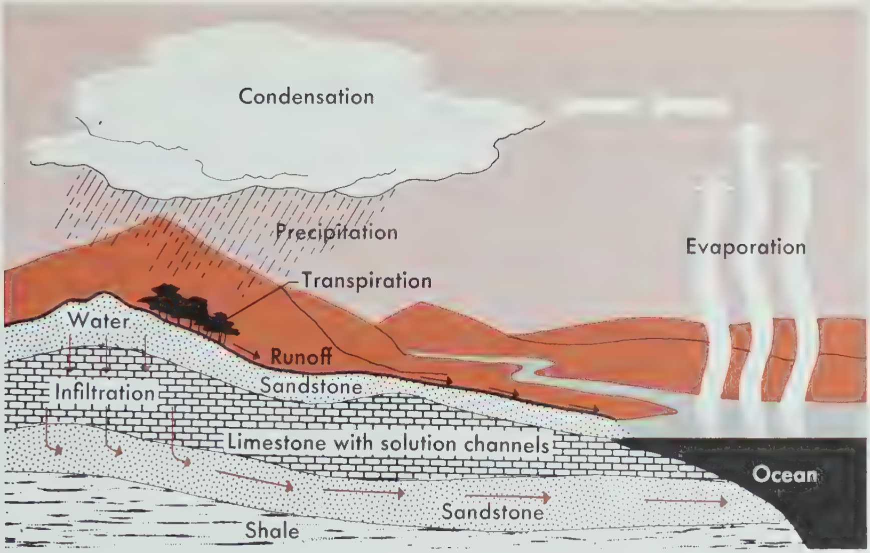


Figure 11-1. Water is continuously carried from ocean to land to ocean again.

EXPERIMENT. Dissolve 1 tablespoon of table salt in 1 cup of water and taste the solution. Pour this solution into a flask. Place the flask on a ring stand over a Bunsen burner, using wire gauze or screen to support the flask on the ring. Insert a flexible drinking straw or plastic or rubber tubing in the hole of a one-hole rubber stopper. Seal the hole with moist clay, if necessary, to insure a closed system. Close the flask with the stopper. Make sure that the straw or tubing is above the surface of the solution. Bend the straw or tubing, and insert the free end through a small hole in a piece of cardboard. Place the cardboard over a water tumbler. Add weight to the cardboard, if necessary, to keep it in place. Surround the tumbler with ice in a shallow pan. (Figure 11–2.)

Bring the solution to a boil. What happens in the straw or tubing? What happens in the tumbler? Continue the boiling until the solution is almost, but not quite, boiled away. Then remove the burner. (Continued application of heat may break the flask.) When the tumbler and the water in it are cool, taste the water in the tumbler. Is it salty? What remains in the flask? Is the combined volume of water left in the tumbler and in the flask the same as the volume you placed in the flask at the beginning of the experiment? Explain your answer.

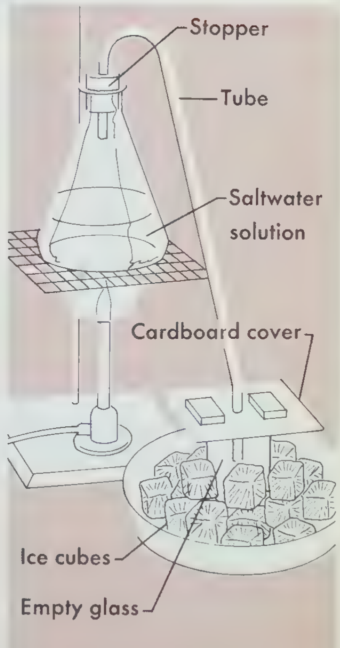


Figure 11-2.

Problems

1. Relate this experiment to the hydrologic cycle. What heat source near the equator is represented by the Bunsen burner in this experiment?
2. In one million years, will the ocean be slightly less salty or slightly more salty than it is now? Why?

3. Why are clouds sometimes seeded with dry ice?
4. You have demonstrated condensation or precipitation in the preceding experiment. You can also demonstrate condensation by holding a cold dish or pan in the steam emerging from the spout of a boiling teakettle. Will moisture continue to condense on the dish until there is no more water?
5. Which would be safer to drink, pond water or freshly collected rainwater? Why?
6. Seawater passing into the air as vapor and later condensing to fall as rain is an example of simple distillation. Distillation, an essential natural process, is also important in industry and is used in the chemical, oil refining, and drug industries as well as in many other applications. Can you name some products of distillation?

11:2 *Composition of the Ocean*

Water is derived from volcanic eruptions and from the consolidation of magma at depth below the surface.

Water for the ocean basins has been formed by consolidation of the earth's matter. When magma cools and consolidates to form igneous rocks, water vapor is given off. Some of this water vapor finds its way to the surface along cracks or bedding planes. Most of the water vapor is carried to the surface during volcanic eruptions. During the 4.5 billion years of the earth's existence, enough water has accumulated to more than fill the ocean basins. Water is still being added to the surface of the earth, but yearly additions are relatively small.

Elements in solution in seawater are derived from weathering of rocks, volcanic eruptions, and the gases of the earth's atmosphere.

Water which is carried to the surface by volcanic eruptions contributes a number of elements in solution. These elements are present in ocean waters in relatively large quantities. Other elements are added to ocean waters by rivers that carry products of rock weathering in solution. Sodium chloride is the most abundant compound in solution in seawater. Sodium is a product of rock weathering. Chlorine is added to the ocean by volcanic eruptions. Ocean water is called *brine* because of the presence of sodium chloride. When sodium chloride is precipitated, it forms the mineral *halite*, or common salt.

Other substances in seawater are calcium, magnesium, sulfur, and potassium; traces of silicon, bromine (broh′meen), and strontium (strahn′chee um); and minute amounts of many other elements. Gases from the atmosphere, including oxygen, carbon dioxide, and nitrogen, also are dissolved in seawater.

River water and seawater differ in composition, although most of the water in the ocean has traveled over the earth's surface as river water. One reason for the difference in composition is that marine life removes some elements from ocean water. River water has a high content of silica (SiO_2) and calcium in solution. Ocean waters are low in silica and calcium because marine life uses these substances for shells, bones, and coverings. Most marine animals use calcium; microscopic marine plants, called diatoms, use silica in their coverings.

Rivers carry small amounts of salt compared to the volume of water. Nevertheless, enough salt is present in river water so that salt lakes may form by concentration through evaporation. Evaporation of ocean water has concentrated the amount of salt in solution until ocean water has become a brine. On a smaller scale, the Great Salt Lake of Utah is undergoing the same process of salt concentration, and is now more concentrated than ocean brine.

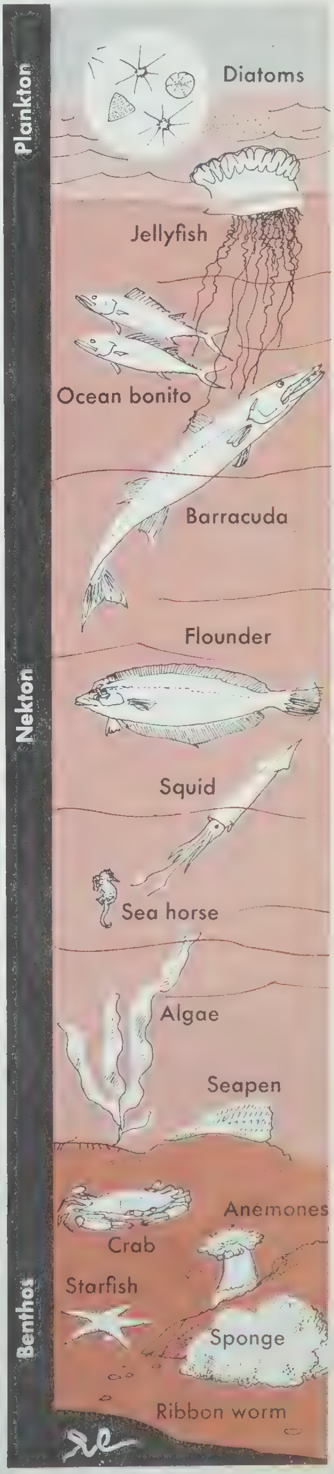
A comparison between the composition of river water and ocean water is difficult. A river's constituents are determined by the kind of rock and soil over which the river and its tributary streams flow. Each river tends to have a different concentration of soluble material. On the other hand, ocean waters undergo a thorough mixing which distributes their soluble material almost uniformly. Thus, oceans have similar constituents, whether at the equator or at the poles.

11:3 *Life in the Ocean*

Living things abound in the oceans. They are classified according to their habits and to the part of the ocean they inhabit. *Nekton* (nek′tan) includes all the swimming forms, from tiny herring to huge whales. *Benthos* (ben′thahs) are creatures such as corals, snails, starfish, and clams, that live on the sea floor. Forms of plant and animal life that float at or near the ocean surface are called *plankton* (plangk′tan).

Life activities are performed easily in the ocean compared to life activities on land. Oxygen for animals and carbon dioxide for plants are dissolved in seawater. Organisms can absorb what they require from the abundant and easily obtainable food supply. Many animals get their nutrients by circulating the food-bearing water through specialized structures of their bodies which are adapted to filtering. Movement requires little energy because of the buoyancy of water. The temperature range is small, and little protection against heat or cold is

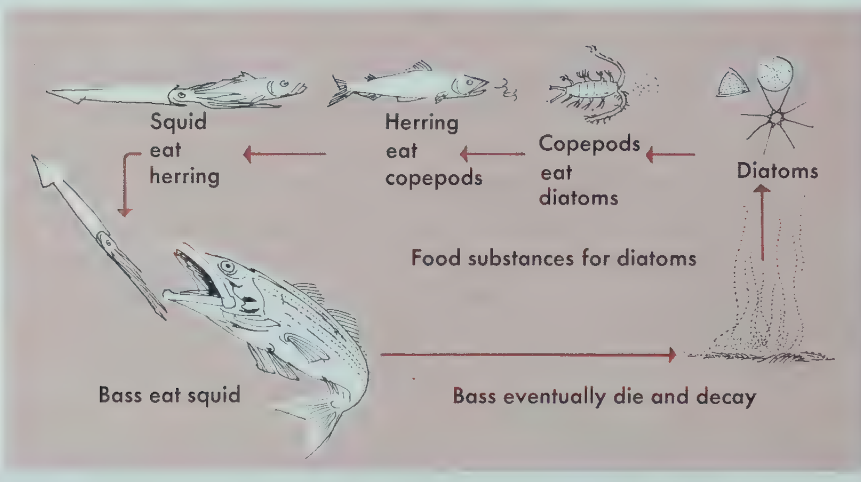
Figure 11-3. All depths of the ocean are populated with a variety of life.



needed. But in spite of the advantages of the sea, few animals in the sea have a long life. Some other sea animal is always ready to use its unwary neighbor for food.

Plants are at the bottom of the food chain in the ocean, as they are on land. They are the food on which all animal life depends, either directly or indirectly. Plants convert sunlight, carbon dioxide, and water into proteins, carbohydrates, and starches by a process called *photosynthesis* (foht a sin′tha-sis). This food energy is used directly by plant-eating animals and indirectly by flesh-eating animals. Because energy from the sun is necessary for the life processes of plants, plant life is confined to the upper zone of ocean water that is penetrated by sunlight. Many plants belong to the plankton, but some sea-weeds live attached to the bottom near the shore.

Figure 11-4. Animals derive most of their food energy from lower forms of life.



Microscopic organisms having some characteristics of both plants and animals are classified as **protists.**

Plankton include several types of floating organisms, many of which are too small to be seen by the naked eye. Microscopic plants and animals, as well as tiny *larvae* (lahr′vee), or young forms of larger animals, belong to the plankton. Some plankton have characteristics of both plants and animals. Like plants, they can manufacture food from sunlight, carbon dioxide, and water; like animals, they can capture food.

Diatoms are at the bottom of the food chain; nekton are at the top of the food chain.

Diatoms (die′a tahms) are small, one-celled plants that make up a large proportion of plankton. Diatoms are important sources of food for many sea animals, including some whales. During spring storms, ocean waters undergo a thorough mixing which brings nutrients and minerals to the surface in large quantities. This abundance of nutrients brings

about a rapid growth of diatoms. In fact, diatoms multiply so rapidly that they may form a colored blanket on the ocean surface. This living blanket provides food for great numbers of marine life. But the nutrients are soon used up, and within a few weeks the blanket of diatoms disappears.

Diatoms form important food supplies for all sea animals.

Benthos, or bottom dwellers, live in shallow water where sunlight penetrates to the bottom. Here food is abundant and little effort or movement is necessary to obtain it. Many animals attach themselves to the sea floor; others crawl or swim slowly about in search of prey. Slow moving animals and those attached to the bottom usually have heavy *calcitic* (kal sit′ik) *shells* covering their soft bodies. Oysters, clams, snails, and several other shelled animals are familiar inhabitants of the shore zone, where food-getting is easy but protection is needed against their neighbors. A shell is little protection against the starfish. A starfish can open another animal's shell, insert a part of its digestive system, and consume the animal without breaking the shell.

Nekton are swimmers and are not limited to a particular environment. Nekton move from one depth to another and from one place to another. Some prefer cold water, and others thrive in warm regions; still others roam the entire ocean. Most flesh-eating nekton live just below the surface, where food is plentiful. Many plant-eating nekton come to the surface only at night to feed on plankton.

American Museum of Natural History

Figure 11-5. The bottom-dwelling sea anemone is shown with its tentacles extended for food gathering (top and right) and withdrawn when disturbed (left).

Figure 11-6. The research vessel Trieste has made many journeys to the ocean bottom.

Official U.S. Navy Photo

Food becomes more and more scarce as water deepens, but probably no part of the ocean is without some organisms. Observers who descended to the bottom of the Mariana Trench in a *bathysphere* (bath′i sfir), a submarine observatory, were amazed to find life at a depth of nearly 36,000 ft. No light penetrates this great depth and water pressures are tremendous, yet organisms manage to exist.

11:4 *Topography of the Ocean Floor*

Challenger expedition was the first scientific exploration of the ocean bottom.

In the past, the ocean bottom was considered to be a smooth, plane surface where no erosion and little deposition occurred. Now oceanographers are beginning to realize how irregular the bottom of the ocean really is. (Figure 11–8.) The first scientific attempt to map the ocean bottom was undertaken by the Challenger expedition, which set out from England in 1872. Although the Challenger collected a vast amount of data during its four years of travel, only a relatively few readings were made on ocean depths, considering the vast size of the ocean. Getting even one sample required many hours of difficult work. Reel after reel of rope or wire had to be unwound and then rewound. Often, just the weight of the wire and the pressure of water broke the line. Then the procedure had to be repeated. Incomplete as it was, data from the Challenger expedition stimulated many new ideas about the ocean bottom. Unexpected irregularities were discovered and important oceanographic research had begun. Now many expeditions have crisscrossed

the ocean and new instruments have been devised for mapping the relief of the ocean bottom.

Mapping the ocean floor requires methods different from those used on land. Land surveyors measure distance and elevation directly. Only indirect methods can be used in the ocean. Mapping is based on echo sounding, seismographic surveys, and sonar or radar methods. All of these methods depend on a similar principle. (Figure 11–7.) Sound, or any other kind of vibrations, will pass from the surface to the ocean bottom at a given angle and be reflected at the same angle to a surface receiver in a given length of time. The velocity of sound in water is approximately 5,000 ft/sec. Depth can then be computed by the following formula:

$$D = \tfrac{1}{2} t \times V.$$

Where D represents depth, t represents time elapsed between sending and receiving the vibrations, and V represents the velocity of the vibrations in water.

PROBLEMS

1. Through its sonar device, a ship determines that a submarine is nearby. How far from the ship is the submarine if the signal is received 4 sec after the initial sound impulse is sent?
2. A mapping ship sends a sound impulse and receives the reflection from the ocean floor 6 sec later. What is the depth of the ocean at this point?

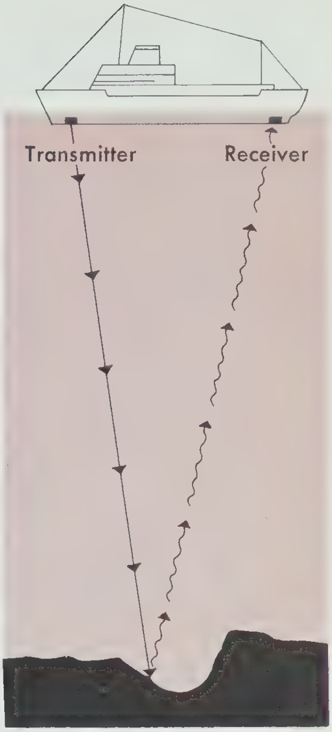
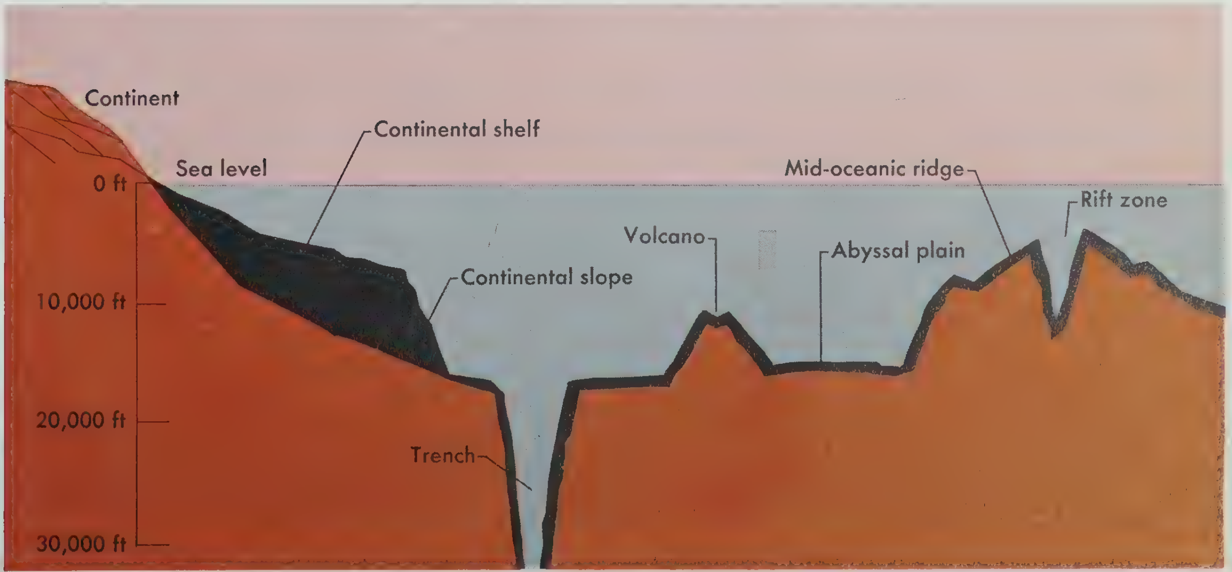


Figure 11-7. Sound waves sent out from the vessel are reflected surfaceward from the ocean bottom.

Figure 11-8. Mountains, plains, and deep trenches of the ocean floor.



Depth is measured from **sea level,** the zero elevation where land and sea meet. Sea level is the average height of the sea, measured over a long period of time, disregarding tides and waves. Land elevations are measured above sea level; ocean depths are measured below sea level.

Echo sounding, sonar, radar, and seismograph surveys are useful in mapping the ocean.

Echo sounding is used to measure depth directly from sound waves. A bell or beeper is sounded at one end of the investigating vessel and the *echo,* or returning sound, is recorded at the other end of the ship. Sound strikes the ocean bottom at a given angle and is reflected or bounced back to the surface at the same angle. *Sonar* detection systems also use this principle. Submarines, for example, are equipped with control devices that pick up and record the return of sound.

Seismographic (siez′moh graf ik) *surveys* require two ships. One ship sets off a charge of dynamite; the other records the time of arrival of seismic vibrations, which are similar to sound waves. Seismographic surveys provide more information than echo sounding or sonar, because seismic vibrations can penetrate rock. Seismic vibrations have a different velocity in each different density of rock. Information about the kind of rock and the depths of different kinds of rock can be determined. From seismographic studies, oceanographers know that, above the mantle, continents are composed of granitic-type rock. But the crystalline rock layer above the mantle in the ocean basin is composed of basaltic-type rock.

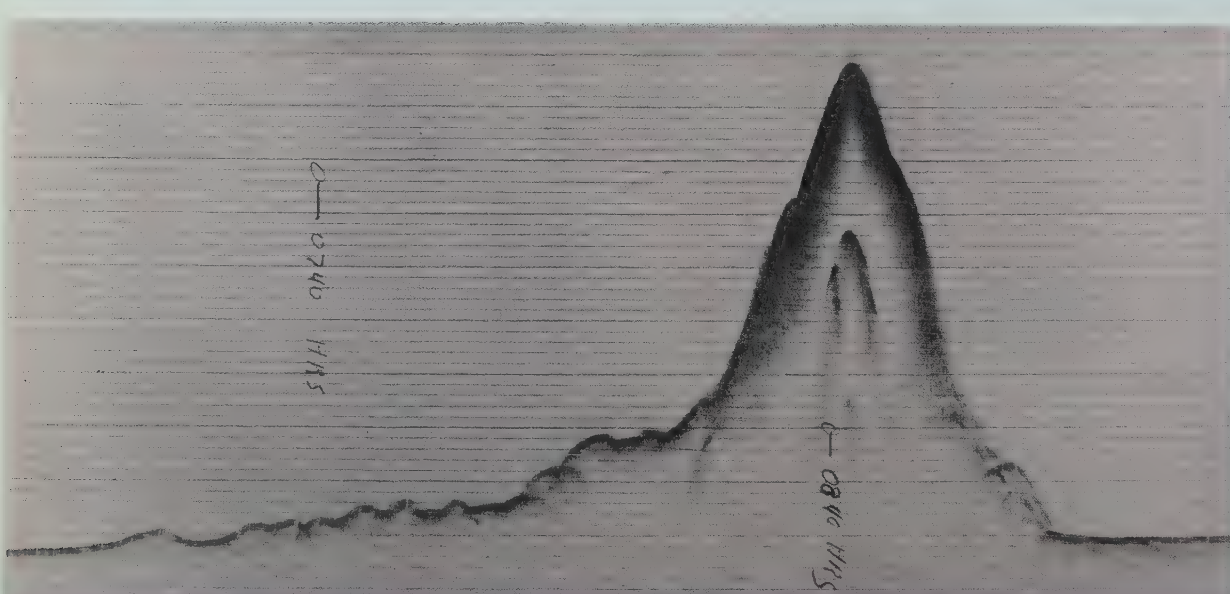


Figure 11-9. The Atlantis Seamount rising 5,400 ft above the sea floor is recorded by this seismic profile.

Woods Hole Oceanographic Institute

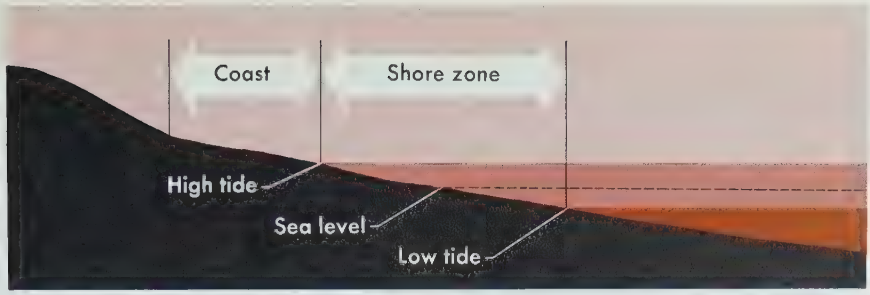


Figure 11-10. The shore zone is alternately covered and exposed as sea level changes with the tides.

Submarines, with their delicate sonar instruments, are particularly important in mapping details of ocean topography. Submarines also have mapped the shape of overlying ice masses in polar regions. Through the use of echo sounding, sonar, and seismographic surveys, the ocean floor has been found to have as varied relief as the continents. Mountain ranges, deep canyons, volcanoes, and plains are found in the ocean depths.

The **shoreline** is the line where land and sea meet. Shorelines represent the average position of sea level, determined over long periods of time. During the geologic past, sea level has not been constant. Seawater moved over the continents and covered much of the land which is now exposed. Seas have also retreated to much lower levels than they now occupy. But during historical times, sea level is considered to have been a relatively constant surface, and it remains the most useful plane of reference from which to measure elevations.

Shorelines always lie within shore zones, and represent a mid-position between maximum tide and minimum tide. The shore zone includes the region lying between high and low tide. This zone varies from day to day, or sometimes from hour to hour, depending on wave height as well as maximum tide. Within the shore zone, materials are in constant motion, moved back and forth by incoming and outgoing waters.

Extending inland from the shoreline to the first major change in topography, lies a strip of land known as the **coast.** A coastal region may be several feet or several miles wide. It actually belongs to the continent, but it is linked to the sea by contact with waves and currents.

The **continental shelf** is that part of the continent which is covered by seawater. The shelf extends from the exposed rocks of the continent to the edge of the true ocean basin. At the present time, water overflows onto the shelf from a too-full ocean basin. The amount of overflow depends on the amount of water in the ocean basin, as well as on the size of the basin. During past geologic time, the width of the submerged shelf has varied

The **continental shelf** is that part of the continent submerged beneath ocean waters.

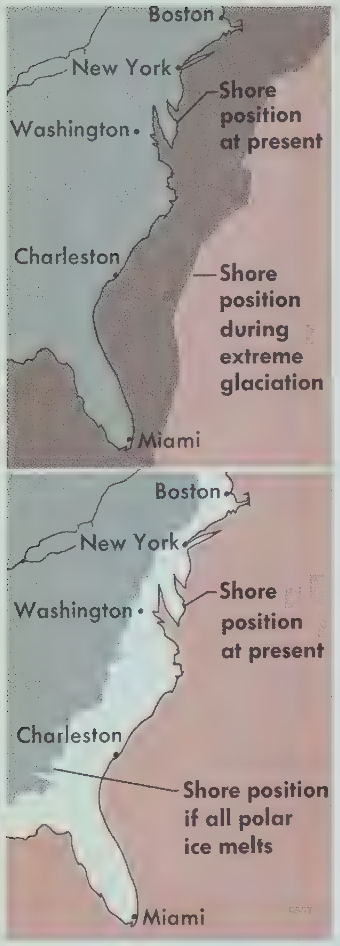


Figure 11-11. Since the great ice age, returning meltwater has raised sea level about 400 feet; melting of all polar ice would raise sea level another 150 to 200 feet. What U.S. cities would be inundated?

with changes in sea level. Changes in sea level have been brought about during periods of glaciation when ice has been trapped on the land. Sea level has also risen or fallen as the ocean basin has been enlarged or filled during mountain building and subsequent erosion of the continents.

The **continental slope** is an abruptly sloping surface that separates the continents from the ocean basin. On its landward side, the continental slope merges with the continental shelf. On its seaward side, the continental slope descends to the ocean basin, where it joins the abyssal plain.

The **abyss** (a bis′) is the floor of the ocean. Its average depth is approximately 15,000 ft. Features of the ocean floor include mountains, trenches, volcanoes, and plains. *Abyssal plains* are almost level areas in the deepest portion of the ocean basin. Great gashes, or *trenches*, cut into the abyssal plain. Trenches of the ocean basin resemble the Grand Canyon of the Colorado River, the most notable surface feature of North America. However, many oceanic canyons are longer and deeper. The Grand Canyon is 4,000 ft to 5,500 ft or nearly one mile deep. The *Mariana* (mar ee an′a) *Trench*, which lies just off the Mariana Islands in the western Pacific Ocean, is at least 36,000 ft or about 7 mi deep. The *Tonga* (tahng′a) *Trench*, in the South Pacific Ocean, is about 35,000 ft deep. Many other trenches are known that are almost as deep as these two. Most of the deep trenches lie close to the edge of the ocean basin in association with volcanic islands just off the mainland.

Innumerable *volcanic peaks* rise from the abyssal plain. Peaks may occur alone or in chains, and some of them extend above sea level to form islands. Other volcanoes that once were islands have sunk below the surface of the sea. Former islands can be recognized by their flat tops, which were eroded by waves while the land was above sea level.

The *mid-oceanic ridge* is the most extensive feature that rises from the abyssal plain. This ridge ranges from 300 mi to 1,200 mi across and extends for 40,000 mi. Its course meanders from the Atlantic Ocean through the Pacific Ocean. Starting from Iceland in the North Atlantic, the mid-oceanic ridge extends southward through the Atlantic Ocean. Then it turns eastward around Africa, and northward into the Indian Ocean. From there, the ridge turns southward again, and passes between Australia and Antarctica and out into the South Pacific Ocean. The ridge passes northward and eventually reaches the coast of Alaska. One branch extends northward to the coast of

North America, where it ends. Some peaks of the ridge reach the surface and form islands; others are covered by several thousand feet of water.

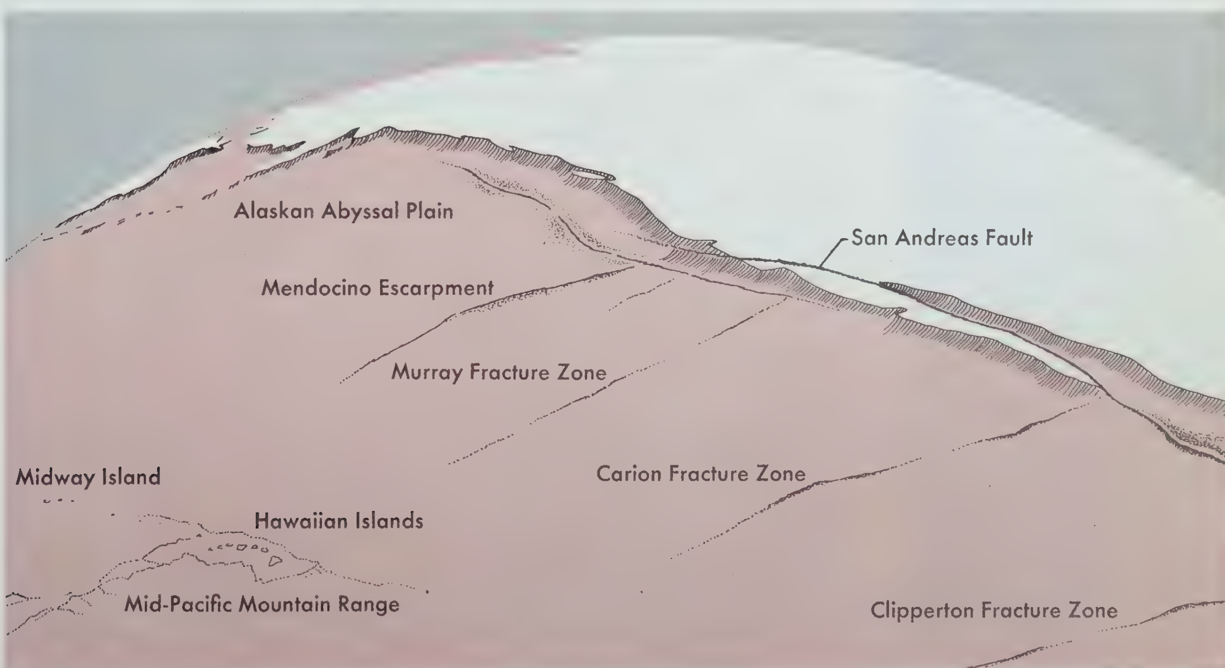
A *rift zone*, or central crack, marks the middle of the ridge throughout its length. Earthquakes and volcanic activity are common within the rift zone. The crack is 20 mi to 30 mi wide, and is bordered by vertical walls that plunge downward for approximately one mile. Many other ridges are present on the floor of the Pacific Ocean, but the mid-oceanic ridge is the grandest mountain chain on the planet earth!

The mid-oceanic range is broken by a steep-walled crack along its axis.

The Pacific Ocean floor is broken by four major cracks, or *faults*, that extend for thousands of miles, roughly parallel to lines of latitude. Many faults are bordered by steep cliffs that indicate vertical movement along the crack. The Hawaiian group of volcanic islands is associated with one of those great cracks. Along the fault, many earthquakes have been recorded just before volcanic eruptions. Such observations suggest that volcanic activity and earthquakes have related causes.

The ocean basin is not a quiet, uneventful environment. Instead, mountains rise from time to time, cracks form, and volcanic eruptions occur. In addition, the ocean basin receives sediments, some of which come from the land, but many of which originate in volcanic activity on the ocean floor.

Figure 11-12. Great faults parallel to latitude break the floor of the Pacific Ocean into huge segments.



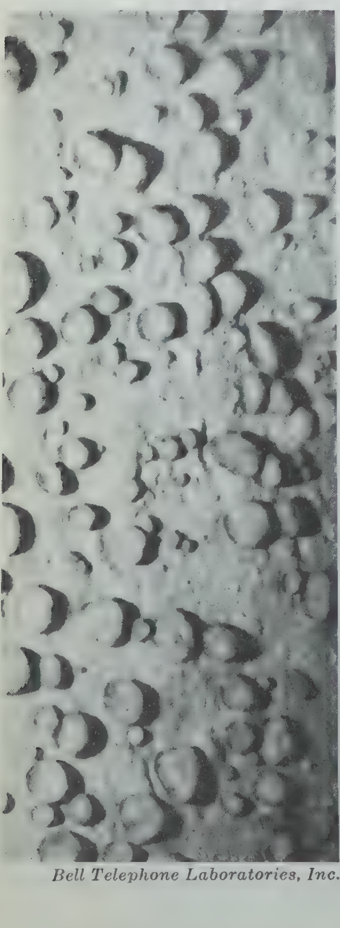
11:5 Deep-Sea Deposits

Deposits in the ocean originate in the erosional debris of the continent, volcanic eruptions on the sea floor, falls of meteoric dust, and shells and coverings of marine organisms.

Sediments cover the ocean floor, except where the slopes of submarine mountains are too steep for the debris to withstand the pull of gravity. The average thickness of sediment is about 2,000 ft in the Atlantic Ocean and 1,000 ft in the Pacific Ocean. Many small hills have been completely covered by sediments.

Approximately 3 billion tons of sediment are dumped into the oceans each year by the rivers of the world. Much of this material remains trapped on the continental shelf, but some is carried into the abyss. Deep-ocean sediment consists of meteoric dust, volcanic ash, some organic matter, and fine material carried seaward by winds.

Figure 11-13. Ball-shaped manganese nodules lie on the sea floor in the abyssal hills at a depth of 3,000 fathoms.



Bell Telephone Laboratories, Inc.

Deposits of the abyssal plain are called **oozes** (ooz′es). At ocean depths of 2,000 ft to 13,000 ft oozes are derived primarily from plankton. At depths of 13,000 ft to 27,000 ft, these deposits contain mostly clay, with some quartz, mica, and iron stain. This material is so fine that individual grains can be identified only by use of X rays. Deep-ocean clay contains little organic matter, because calcitic shells go into solution in deep waters. Carbon dioxide, which is in solution in relatively large amounts, together with the great pressure of the water increase the solubility of calcite. Shark teeth and fish ear bones are two of the few recognizable animal remains.

Shells of calcite and coverings of silica overlay about half the ocean floor. This material is called **calcareous** (kal kar′ ee us) **ooze** or **siliceous** (si lish′us) **ooze,** depending on which type of material is most abundant. Siliceous ooze, which comes from diatom coverings, is less abundant than calcareous ooze. However, some deposits of *diatomaceous* (die et a mae′ shus) *earth* have been found on what is now land area, indicating that deep-water deposits have been uplifted above sea level. Diatomaceous earth is a fine material which is used in filters and as an abrasive in toothpaste.

Meteoric dust, or "star dust," falls into the ocean and accumulates as part of ocean sediment. On land, such materials mingle with the soil and cannot be recognized. The meteoric origin of the oceanic dust is quite apparent and gives a clue to the total amount received by the earth. Other interesting materials found in the deep sea are manganese and iron **nodules** (nahj′ools), or lumps. Both manganese and iron are precipitated around cores of animal remains. Manganese is necessary

to the manufacture of steel. Since the supply of manganese on land is limited, perhaps someday the steel industry will use nodules from the sea floor as the main source of manganese.

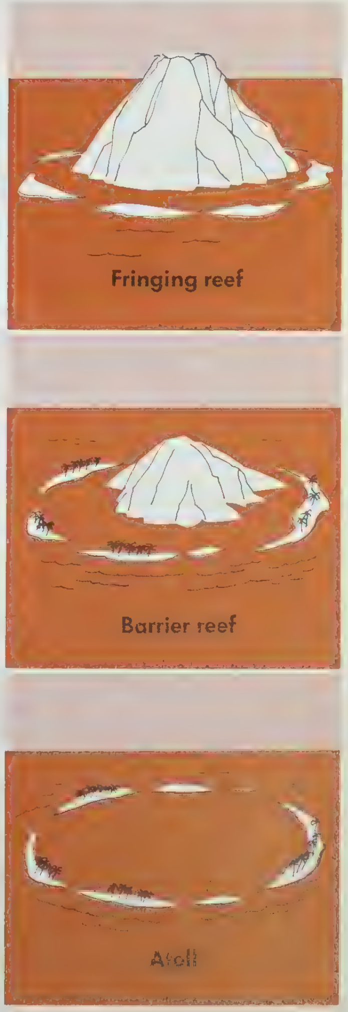
Coral reefs are deposits which usually occur in relatively shallow water and around mid-ocean volcanic islands in the Pacific. Reefs grow on solid rock in water below low tide level and no deeper than 150 ft. Coral is made from the skeletons and shells of tiny marine animals that live in colonies or apartment-like structures. Reefs occur only where water is salty, shallow, and clear. The water must be between 20°C and 26°C (68°F and 78°F) and be circulating freely to bring food to the stationary animals. Conditions favorable for reef growth occur in only a few parts of the ocean.

Reefs are begun when a coral attaches itself to a rock and then builds a shell around its body. This first shell serves as a base on which other marine animals can build. If the water is too deep, sunshine is not available and the organisms cannot live. If the water is too shallow, organisms may die because water circulation is insufficient to bring them their food. As corals multiply, many kinds of marine life are attracted to the reef. *Fringing reefs* grow on the borders of islands in mid-ocean or along the borders of continents where the continental shelf is especially narrow. *Barrier reefs* are built offshore at the edge of a wide continental shelf. They are separated from the mainland by a stretch of open, quiet water called a *lagoon*. An *atoll* (a′ tawl) is a ring of coral surrounding a lagoon. An atoll may be the last remnants of a fringing reef built around a sinking volcanic island or a new reef just beginning to be built around a rising island.

Geologists are especially interested in reefs because much of the world's oil has been found in ancient reefs. In many regions, these reefs have been buried beneath later sediments, and wells must be drilled to depths of thousands of feet. Reefs record changes in sea level in their pattern of growth. In shallow water, reefs tend to grow outward toward the deeper ocean. In deepening water, reefs grow upward, sometimes for several thousand feet. If sea level rises, reefs may grow landward.

In spite of the vast size of the ocean and the great variety of its topography, ocean waters are surprisingly uniform in composition. Currents, tides, and waves are in constant motion, distributing heat and nutrients throughout the length and breadth of the ocean.

Figure 11-14. Coral reefs growing upward on the slopes of a subsiding volcanic island.



MAIN IDEAS

1. The hydrosphere includes water in the oceans, water vapor in the atmosphere, and all surface and near-surface water of the continents.
2. Sediments that accumulate on the continental shelves originate on the continents as a result of weathering and erosion of exposed rocks and are carried to the ocean by wind and rivers where they are deposited.
3. Most of the water of the hydrosphere probably was formed during volcanic eruptions and the cooling of the magma.
4. Ocean water contains elements derived from weathering of rocks, and from volcanic eruptions on the sea floor. Sodium chloride is the dominant compound in solution in seawater.
5. Marine life is classified by its habits and its environment. Plankton include floating protists, plants, and animals; nekton include swimming marine life; benthos include bottom dwellers.
6. Energy from the sun is made available to all marine life through photosynthesis, a life process of plants.
7. Shoreline is that line where land and sea meet along the average sea level.
8. The shore zone includes the region between high and low tide where sands are constantly moved about.
9. The continental slope is the steeply sloping boundary between continental shelf and ocean bottom.
10. The abyss is the deep part of the ocean, averaging about 12,000 ft to 15,000 ft deep, and marked by trenches 30,000 ft to over 36,000 ft deep. From the floor of the abyss rise volcanic mountains and mountainous ridges which extend for thousands of miles. The major ridge is the mid-oceanic ridge that extends through both the Atlantic and Pacific oceans forming a continuous mountain range that is about 40,000 mi long.
11. Deep-ocean sediments include clay, calcareous and siliceous oozes, small amounts of organic matter, and nodules of iron and manganese.
12. Shallow water sediments include rock fragments, sand, and mud carried to the sea by rivers, and limestone derived from shells and precipitates of marine organisms.

13. Marine organisms may build extensive reefs in warm, freely circulating, salt water which is no deeper than 150 ft. Ancient buried reefs often contain important petroleum deposits.
14. Although the ocean has many different characteristics, its composition remains fairly constant because of its continual circulation.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

abyss	lagoon	nutrient
atoll	larvae	ooze
benthos	mid-oceanic ridge	plankton
diatom	nekton	seismic
hydrologic cycle	nodule	shoreline

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Water vapor in the atmosphere is a part of the hydrologic cycle.
2. Gases from the atmosphere are dissolved in ocean water.
3. Most river water contains only small amounts of salt in solution.
4. The Challenger survey proved that the ocean floor is not a smooth, plane surface.
5. Sea level never changes.
6. Volcanic activity and earthquakes are associated with the rift zone of the mid-oceanic ridge.
7. The amount of carbon dioxide in seawater increases as depth increases.
8. The Hawaiian Islands are true coral reefs.
9. Diatomaceous ooze is made of silica and clay.
10. No meteoric dust can be recognized in deep-sea sediments.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Whales are members of the (*plankton, benthos, nekton*).
2. Diatoms are classified as (*plankton, benthos, nekton*).
3. Oysters are classified as (*plankton, benthos, nekton*).
4. Water from the ocean basin overflows the continent on the (*continental shelf, continental slope, abyss*).
5. An island that lies on the mid-oceanic ridge is (*Greenland, Iceland, Newfoundland*).
6. Eventually the steel industry may use deep-sea deposits of (*manganese, calcium carbonate, magnesium*).
7. Rock density of the ocean floor is determined by means of (*seismographic surveys, echo sounding, sonar devices*).
8. Ocean floor deposits at depths over 20,000 ft might contain (*shark teeth, oyster shells, whale skeletons*).
9. Most of the sediment from the land is deposited in the ocean on the (*continental shelf, continental slope, abyss*).
10. Reefs built around volcanic islands of the Pacific are called (*fringing reefs, barrier reefs, atolls*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. When sodium chloride crystallizes from a solution, it forms the mineral __?__.
2. Fish use less energy for food-getting than land animals because of the __?__ of the water.
3. The most abundant plankton are the __?__.
4. Animals that attach themselves to the bottom of the ocean in the near-shore zone are called __?__.
5. Echo sounding is a method of mapping the ocean bottom which uses __?__.
6. Coverings of diatoms are made of __?__.
7. Coral reefs are predominantly made of __?__.
8. Fine-grained deposits on the ocean floor are called __?__.
9. Velocity of sound in water is __?__.

10. The average height of the sea or zero elevation where land and sea meet is called ___?___.

D. How and Why

1. Folklore tells about the mysterious appearance or disappearance of islands in the ocean. Is there any basis for such tales? Discuss possible reasons for occurrences of such islands.
2. If the hydrologic cycle continuously brings fresh water to the continents, why should desalting of ocean water be considered necessary for future water demands?
3. If you planned to take a core sample from the mantle of the earth, where would you drill in order to go through the least amount of crustal material?
4. Discuss some of the difficulties of underwater exploration.
5. Would you expect to find coral reefs growing around the volcanoes off the coast of Alaska? Explain your answer.
6. What information can be obtained from a seismographic survey that cannot be determined by echo sounding or sonar recording?
7. What is the origin of the sediments that accumulate in the shore zone? Discuss the changes that granite undergoes in order to furnish sediment to the continental shelf area.
8. What happens to the carbon dioxide in solution in seawater? Why is carbon dioxide less abundant in the near-surface waters?
9. Why can the percentage of meteoric dust in deep-sea ooze be determined although there is little evidence of meteoric dust on the continents?
10. Suggest reasons why Florida has its coral reefs growing around the area of the Keys, but the Louisiana and Texas coasts have no comparable coral development.

INVESTIGATIONS

1. Report on some inhabitant of the sea that you find especially interesting.
2. Read the authentic information about whales in the complete edition of *Moby Dick* by Herman Melville.

3. Arrange a display of various seashells or fossil shells and plant impressions from lake shores.
4. Prepare a report on the studies conducted by underwater explorers living in capsules below sea level. How have these explorers made use of marine animals?

INTERESTING READING

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Carson, Rachel, *The Sea Around Us*, rev. ed. New York: Oxford University Press, 1961.

Idyll, C. P., *Abyss: The Deep Sea and the Creatures that Live in it.* New York: Thomas Y. Crowell Company, 1964.

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Circulation of Ocean Water

Circulation of ocean water resembles the circulation pattern of the atmosphere. Water, heated at the equator, expands and spreads out on the surface. At the poles, cold, dense water sinks to the ocean floor and flows toward the less dense waters of the equator. But currents are not simple north-south movements. Like air, ocean waters are deflected by the rotation of the earth.

Circulation of ocean water influences the climate of the earth and warms the land adjacent to the sea. Currents distribute both heat and dissolved substances from place to place. Currents are responsible for distributing food to marine animals.

12:1 *Major Circulation Patterns*

Surface currents are initiated in the tropics by the powerful trade winds and by differences between the density of tropical waters and polar waters. Furthermore, sea level is slightly higher in the tropics than in polar latitudes and water tends to flow down this slight decline. Sea level is a few inches higher in the tropics because daily rainfall adds water to the surface of the sea faster than the water can spread out horizontally. Also, heat from the sun causes tropical waters to expand and to have a greater volume than polar waters.

In the tropics, currents flow westward until they meet the continents, then poleward, then eastward, and finally southward to the tropics.

Trade winds blow steadily from northeast to southwest in the northern hemisphere; they blow from southeast to northwest in the southern hemisphere. Trade winds drive the ocean waters before them. But rotation of the earth deflects ocean currents even more than it does air currents. Movements at the surface of the sea is almost due west in the zone of the trade winds.

When the westward moving currents meet the continents that lie across their paths, some water is turned toward the north and some toward the south. Along the eastern coast of North America, the Gulf Stream carries water northward. The Brazil Current moves water southward along the eastern coast of South America. Similar currents in the Pacific Ocean carry water along the eastern coast of Asia. (Figure 12–1.)

In both hemispheres, the surface currents move poleward until they reach the zone of the westerly winds. Then the currents are carried eastward in front of the westerlies until they meet another continent. When eastward moving currents come in contact with a continent, some water flows poleward; the rest flows toward the equator and, in the zone of the trade winds, meets and joins the westward flowing currents. Major surface currents follow a circular path around a central, relatively quiet body of water in both the Atlantic and Pacific oceans. (Figure 12–1.) Within this quiet zone, circulation is too slow to supply food for marine organisms.

Figure 12-1. The complicated patterns of ocean surface currents are caused by the force and direction of the winds and the land masses which act as barriers to the currents.

Deep ocean currents begin their movement in the polar regions. Cold, dense water slides toward the bottom of the sea and then flows slowly toward the equator. However, some water flows just beneath the surface currents but in the opposite direction. Movement of cold, dense water is always toward regions of lower density. As water moves at depth toward regions of lower density, some of the replaced water is forced toward the surface.

Upwellings or **rising currents** of cold water carry unused nutrients to the surface and make them available to plankton. The Grand Banks of the North Atlantic have an abundant fish population due to such upwellings. Another famous upwelling occurs just off the coast of Peru in the Pacific Ocean. Here strong winds blow from the coast and send surface waters flowing oceanward. Water rises from great depths to replace the surface water which has moved away from the shore.

Upwellings of cold water bring a supply of food for plankton, and they, in turn, become food for fish. Because of the abundance of fish, hosts of birds nest along the nearby coast. Bird droppings are the basis for a large-scale fertilizer business, and the abundance of fish makes fishing an important industry. Occasionally the upwelling ceases, and this causes a widespread depression in both the fertilizer and the fish industries throughout coastal areas of Peru and Chile.

EXPERIMENT. Put several dozen ice cubes in the center of a large pan and fill it with water. Heat the water with an immersion heater placed just below the surface, or with a Bunsen burner placed at one side of the container. Add a cinnamon candy or food coloring to the water close to the heater. Draw a diagram to illustrate the movement of the color. What kind of currents are these? What causes the movement?

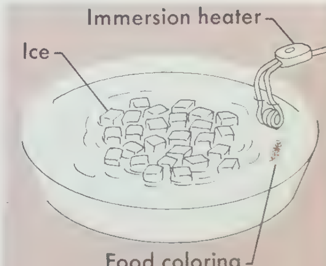


Figure 12-2.

12:2 *Local Currents*

Both major surface currents and deep ocean currents are due to differences in density. But **density currents** occur whenever and wherever some ocean water becomes heavier than adjacent water. Many local density currents are present in the ocean. Some of these currents are complex and cannot be traced by present methods. Others have been recognized by navigators for many years.

Differences in density cause the major circulation pattern and many local currents in the ocean.

Seawater becomes less dense as it is heated, or diluted by fresh water from rivers or rain.

Seawater becomes more dense as it is cooled, as evaporation occurs, and as surface waters freeze and leave salt behind.

Differences in density may have several causes. When surface ice melts, as it does during the summer in polar regions, the meltwater dilutes the ocean brine and makes it less dense than normal. Seawater also may be diluted by rivers where they empty into the sea. Excessive rainfall may add fresh water to the surface of the ocean and make it less dense. On the other hand, increased density occurs when water freezes over wide areas. Salts originally present in seawater are precipitated, then dissolved by water just below the ice. Evaporation also tends to concentrate brines and make them more dense. As water is removed by evaporation, the dissolved salts are concentrated in a smaller volume of seawater, which becomes more dense.

A density current due to evaporation is located in the Mediterranean Sea. Across the Straits of Gibralter, a submarine ridge causes the Mediterranean Sea to be an evaporite basin which is almost isolated from the Atlantic Ocean. Because few rivers flow into the Mediterranean Sea, little fresh water is added. Furthermore, the warm dry climate of the region causes evaporation of an enormous quantity of water. Without additions of fresh water, the Mediterranean brine becomes more and more dense. As the dense surface brine sinks to the bottom, it pushes the bottom layer of water across the ridge and out into the Atlantic Ocean. This deep current of heavy brine spreads westward as far as the Bahama Islands. At the surface, water from the Atlantic flows across the ridge and into the Mediterranean Sea to replace water lost at depth. During World War II, many submerged German submarines escaped

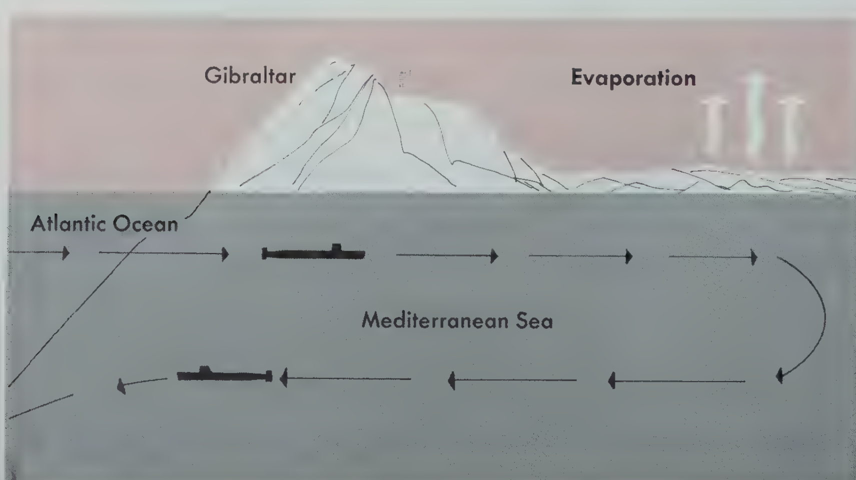


Figure 12-3. In the Mediterranean Sea, currents flow toward the Atlantic at depth, and from the Atlantic at the surface due to difference in density.

detection by turning off their engines and silently riding the currents into and out of the Mediterranean.

Turbidity (tur bid'it ee) **currents** are unique density currents made dense by suspended mud and sand. Turbidity currents flow across and erode the ocean bottom. Many gorges are present on the continental shelf, on the slopes of submerged volcanoes, and on the continental slope. These gorges resemble river valleys. Some of them appear to be extensions of channels of large rivers such as the Mississippi, the Congo, and the Ganges. During flooding, such rivers carry large quantities of sediment from the land to the sea. Flood waters then may be heavier than the ocean brine and continue to flow across the shelf and slope as rivers of mud. Such rivers of mud are called turbidity currents. They scour out channels on the ocean bottom as they flow across it.

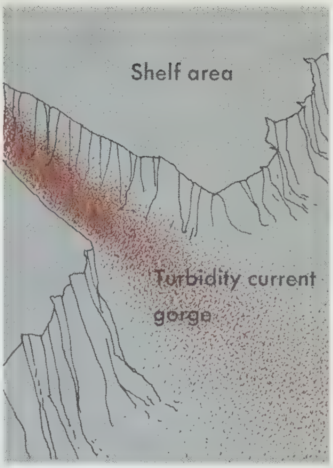


Figure 12-4. Turbidity currents erode channels along the continental slope.

Not all gorges or channels, however, are associated with rivers. Many channels begin rather abruptly at the edge of the continental slope, or they occur on submerged volcanoes in mid-ocean. The first clue to the origin of such channels was supplied in 1929 during an earthquake off the coast of Newfoundland. Immediately following the quake, telephone and telegraph cables on the ocean floor broke. Cables nearest the center of the earthquake snapped first; others broke at successive intervals and distances. In regular succession, breaks occurred in cables lying farther and farther away from the center of the quake. Apparently the earthquake vibrations caused sediments lying on the steep continental slopes to slump downward, just as materials do during landslides in mountainous areas of the continents. At the foot of the continental slope, a great bulge of debris was deposited. Deposits consisted of coarse sand, gravel, and shallow-water fossils. These coarse materials were out of place among the ooze and clay of the abyss. Undoubtedly, this debris had been carried to the ocean depths by turbidity currents. The velocity of the currents was reduced at the foot of the slope, and the materials were dropped in a fan-shaped bulge. Similarly shaped deposits may be found at the foot of steep mountain slopes on land.

Some turbidity currents are associated with rivers from the continent; some result from landslide-type slumps.

Turbidity currents deposit fan-shaped bulges at the foot of the continental slope.

Discovery of turbidity current deposits has helped geologists to interpret similar deposits of rock now found exposed on continents. For example, many rocks now exposed in the California mountains appear to be deposits made by turbidity currents. Apparently the rocks were uplifted during mountain building and later uncovered by weathering and erosion.

12:3 Ocean Waves

Oscillatory waves are deep water waves in which water particles orbit in a circle.

Ocean waves are *undulating* (un′ja laet ing), or alternately rising and falling, movements of seawater. Waves may be produced by forces in any body of water. In the sea, waves may be initiated by winds, earthquakes, or tides.

Deep-water waves are called **oscillatory** (ah sil′a tohr ee) **waves** because the water fluctuates or swings from a high to a low to a high point. In deep water, the wave itself moves forward, but the water particles remain in place. Water particles travel in circles and return to their starting points as the wave moves onward. The diameter of the orbit of the surface water particles is exactly equal to the height of the wave. Below the surface, water particles move in smaller and smaller circles. (Figure 12–6.) Energy is lost as motion is passed downward from one water particle to another. Eventually, at some depth, all energy has been used and motion ceases.

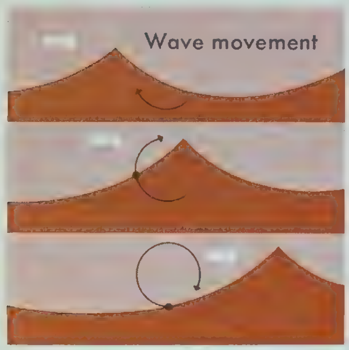


Figure 12-5. A water particle moves upward with the wave crest, then downward with the trough.

Waves are described by several features. The *crest* is the highest point of a wave; its lowest point is the *trough*. *Wave height* is the vertical distance between crest and trough. *Wavelength* is the horizontal distance between successive crests, or successive troughs. *Wave period* is the length of time required for successive crests (or troughs) to travel past a given point. Therefore, wavelength and wave period are dependent upon one another. *Wave base* is the depth at which wave motion ceases. (Figure 12–6.)

In mid-ocean depths, where water particles complete their orbits without contacting the ocean bottom, most waves are deep-water waves. But tides are **shallow-water waves**, even in

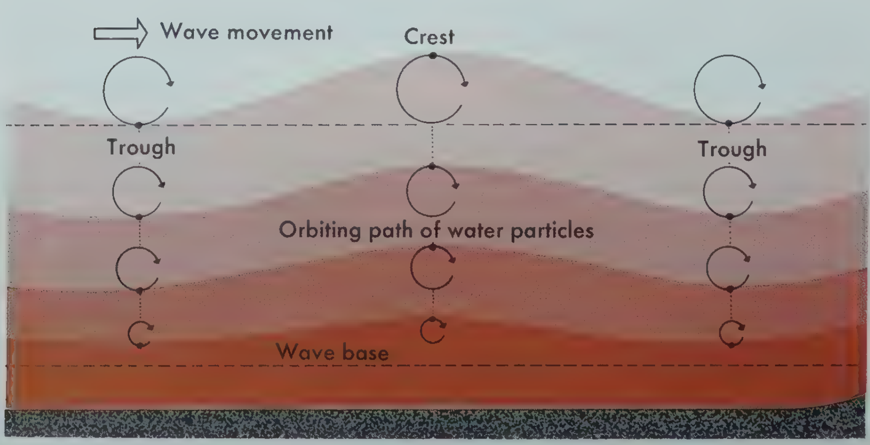


Figure 12-6. In deep water, a particle orbits in place, but the wave form moves onward.

mid-ocean. Their wave base is so deep that even 15,000 ft of water is a depth that is less than half the wavelength. Shallow-water waves form where depth of water is less than half the wavelength. Unlike deep-water waves, shallow-water waves come in contact with the bottom, so that water particles cannot complete their circular orbits. Instead, the water particles are slowed down at the bottom of the orbit, which becomes an ellipse. The elliptical shape of the orbit increases the wave height. (Figure 12–7.)

Shallow-water waves come in contact with the ocean bottom and break, or topple over.

Tides are shallow-water waves in mid-ocean, but wind-formed waves are oscillatory waves. Wind formed waves are shallow-water waves only when they reach the continental shelf. There water depths range from about 200 ft to zero feet at the shoreline. Waves strike bottom somewhere within these depth ranges.

The first line of waves to strike bottom is slowed down. But the velocity of the following waves is not changed, and the distance between waves is shortened. As wavelength decreases, wave height increases. The volume of water that originally was spread out over the longer wavelength is compressed into the shorter distance. Water can only rise and, as a result, water piles higher and higher until it is pulled down by gravity. As the crest falls, all the wave energy is directed toward the bottom. Each wave tumbles, strikes bottom, and stirs up loose debris. The zone in which waves first fall is known as the *breaker zone*. Between the first breaking wave and the shore, in the *surf zone*, waves form and re-form many times. Each new wave eventually arrives in water too shallow for its wavelength. It falls, re-forms, and falls again. Loose debris is tossed

Energy of breaking waves is directed toward the bottom where loose material is eroded.

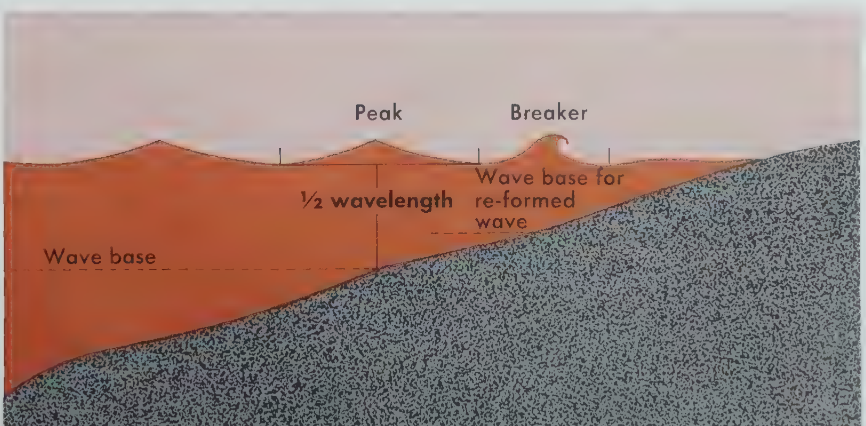


Figure 12-7. In shallow water, the wave base comes in contact with the bottom, causing waves to break.

into the following wave and carried forward a short distance. Sand is always in motion in the water between the breaker zone and the shoreline.

Wind waves are caused by air that blows across bodies of standing water. Wind moves in a turbulent or tumbling fashion because of differences in temperature and pressure from place to place. Warm air rises, cold air descends, and air moves toward areas of least pressure. Many of these differences are local and, consequently, air is always in motion—upward, downward, and forward. Turbulent motion is passed on to the surface of the water as water particles are pushed downward and forward by the wind. Once waves are started, they increase in height as more and more surface comes in contact with the wind. Some time is required before waves develop a regular pattern. But once established, waves continue to move forward long after the wind ceases to blow. Energy is transferred from wind to water. Movement persists until all of the energy has been used by motion or by friction. The height of the waves depends on wind velocity, size of the water body, and length of time the wind blows.

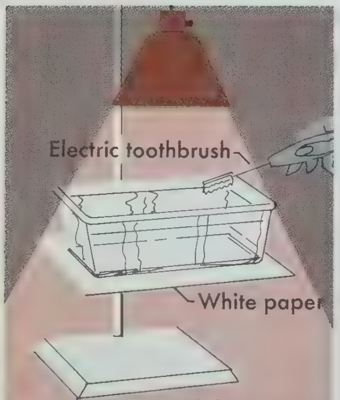


Figure 12-8.

EXPERIMENT. Put a large piece of white paper on a ring stand. Set a pyrex loaf cake pan filled with water on the paper. Turn on an overhead light source so that it shines directly on the pan without casting a shadow. Now start an electric toothbrush vibrating and immerse the brush just beneath the surface of the water. Observe the waves as they begin to move, and as they reach the edge of the pan. What happens to the waves as they reach the far end of the pan? What happens to the waves as they reach the sides of the pan? Observe the white paper beneath the pan. What pattern do the shadows of the waves make? Which waves are reflected? Are any waves refracted or bent? Does the speed of the waves increase or decrease with distance from the source of vibration?

A **tsunami** (seu nahm′ee) is a unique wave that is caused by a rapid shift of the ocean floor during an earthquake. Some tsunamis may be associated with volcanic eruptions, because volcanic activity is often preceded by faulting. Vibrations set up by an earthquake cause water to move back and forth, or oscillate. Minor earthquakes initiate small waves, but major earthquakes produce waves that may travel halfway around the earth.

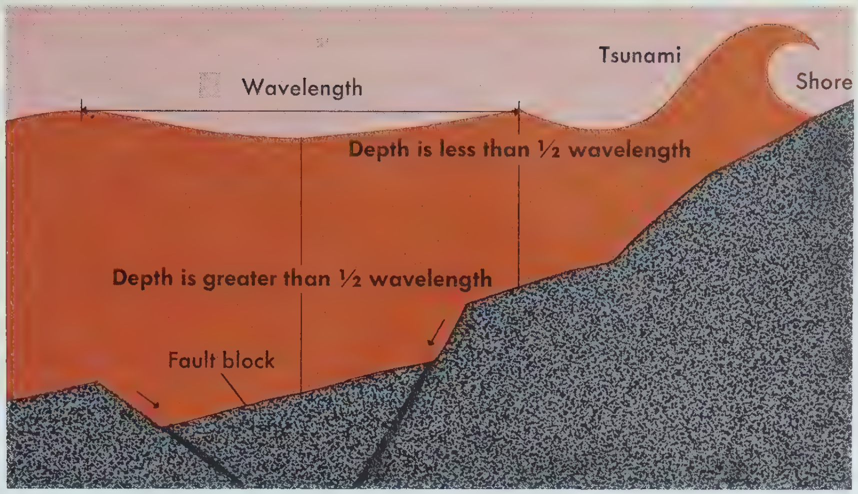


Figure 12-9. As the tsunami approaches shallow water, the wave crest heightens and a great wall of water washes over the shore.

In mid-ocean, the tsunami is no higher than many wind waves. But the wavelength is great and the wave base is deep. Each wave includes tremendous amounts of water that crash against the shore in shallow water. On shore, no ocean disturbance is more destructive than a tsunami, or *seismic sea wave*. The first indication of the approach of a tsunami is withdrawal of water from the shore zone. Withdrawal accompanies the arrival of a low trough. Next a great crest arrives, often with a towering wave capable of carrying ocean liners onto the shore and leaving them stranded. No protection is possible from such immense waves. Safety lies in leaving the area before the waves arrive.

Tsunami waves cause great destruction when they reach shore because their wave base is very deep, and the waves are very high.

Today when an earthquake occurs, it is recorded by seismographic stations which cooperate throughout the world to warn coastal towns of the danger of an approaching tsunami. Notice of the earthquake is sent to all coastal stations that measure tides. Stations are requested to report unusual water levels which might indicate that a seismic sea wave is developing. If any unusual wave heights are reported, all coastal cities and towns are warned. Close cooperation between seismographic stations makes it possible to estimate the travel time and to predict when the tsunami will arrive at various cities in its path. During the Chilean earthquake of 1960, early warning of the approach of the tsunami saved many lives. Hilo, Hawaii, suffered extensive damage from 15-ft waves that swept away much of the city. However, the warning arrived in time, and there were few victims. When the same great wave reached Japan, either the warnings were not heard or they were ignored, and 180 people died.

12:4 *Tides*

Tides, like tsunamis, are waves that travel across the ocean. Unlike tsunamis, tides are a daily occurrence and not destructive. **Tides** are rhythmic movements of ocean water caused by the gravitational attraction between the earth, moon, and sun. Tides are waves with exceptionally long periods and great wavelengths. Crests reach shore approximately 12 hours apart, although this period varies somewhat from day to day. Tides affect the ocean from surface to bottom. Actually, tides are shallow-water waves, because their wave base comes in contact with the ocean floor. However, in mid-ocean the tide is not distinguishable from a normal wind wave. Only when the tide approaches the shoreline can the rise and fall of water be observed.

Tides are shallow-water waves because their wave bases reach bottom, even in mid-ocean.

On low, gently sloping shores, tides move in and out with little effect. But on irregular coastlines, tides may be exceptionally high. For example, tides rise over 40 ft in the Bay of Fundy, Nova Scotia. Here the incoming water advances

Figure 12-10. Bay of Fundy tides are among the highest in the world: a. high tide, b. low tide.

NFB Photos by G. Blouin

through a small opening into a funnel-shaped bay. Water cannot return readily to the ocean because it is confined by the land along the opening and blocked by the advancing tide. Eventually, the water returns to normal sea level, as the tide goes out. Along the nearby coast, where the shore is wide and smooth, the tide rises only one or two feet. Such irregular heights in the tides are due to the shape of the coast.

Tides are bulges of water which form on earth at all times. A large bulge forms on the side of the earth facing the moon; a smaller bulge forms on the side away from the moon. Water that fills the bulges is drawn from the area between them.

Both the moon and the sun attract the earth and produce tides. However, the effect of the moon on the tides is much greater than the effect of the sun because the moon is so much closer. The distance from earth to sun is approximately 93,000,000 mi. Compared to these millions of miles, the 8,000-mi diameter of the earth is extremely small. Consequently, the sun's gravitational attraction for the earth is distributed fairly evenly over the entire earth. By contrast, the moon is only 238,857 mi from the earth, and has a strong attraction for the near side of the earth and a weaker attraction for the far side. Recall that the gravitational attraction between two bodies decreases in proportion to the square of the distance between them. (Section 1:3.)

High tides occur on the side of the earth facing the moon.

A lesser high tide occurs on the side of the earth away from the moon.

Due to the moon's gravitational attraction, a bulge of ocean water always faces the moon. Water particles from adjacent areas add to the bulge as they flow toward this position of greatest attraction. All the earth's matter is attracted to the moon, but solid rock particles cannot flow readily. The portion of the earth's crust facing the moon rises only a few inches in response to the moon's attraction. On the other hand, water rises several feet. A major high tide represents the difference between the crust and ocean bulges.

On the side of the earth away from the moon, a second bulge of water occurs. This bulge results partly from centrifugal force developed during the earth's revolution around the sun. Recall that centrifugal force causes a revolving object to tend to fly away from the center around which the object revolves. (Section 1:4.) The earth itself has developed an equatorial bulge due to the centrifugal force developed by rotation on its axis. (Section 2:1.) The tidal bulge, however, results from the centrifugal force that tends to carry the earth away from its position in the solar system. At the same time, earth's position is

fixed by the gravitational attraction between earth and its moon and between earth and the sun.

On the far side of the earth, centrifugal force overbalances, to some extent, the effect of gravity. A bulge of water occurs as water from adjacent areas moves toward this position of maximum centrifugal force. Some scientists believe that rock particles on the ocean floor are pulled toward the moon, because the ocean floor on the side away from the moon is closer to the moon than the ocean surface. (Figure 12–11.) They believe that a slight depression exists on the sea floor and causes water to rush in and pile up to form the bulge. However, centrifugal force is probably the controlling or major influence in this tug-of-war between opposing forces.

Although the moon is the dominant force causing tides, the sun has some effect on the tides. When earth, sun, and moon are in line with each other, the added gravitational attraction of the sun causes especially high tides called **spring tides**. Spring tides occur twice each month, when the sun and moon are lined up on the same side or on opposite sides of the earth. When the sun and moon are at right angles to each other, their forces of gravity tend to counterbalance. Then bulges are less than normal and the tide is called a **neap tide.** Spring tides occur during the full moon and new moon positions. Neap tides are associated with first-quarter and third-quarter moon positions.

Figure 12-11. Maximum tides occur when sun and moon combine their gravitational pull; minimum tides occur when they pull in opposite directions.

Tidal bulges are in approximately the same position on earth, relative to the sun and moon, at all times. But because the earth turns on its axis, different points on earth are affected by the high and low positions of the tides. As the earth turns on its axis, it passes beneath the bulge facing the moon, then beneath a low tide, a second high tide, and a low tide, and back to high tide again. This complete tidal cycle requires approximately 24½ hours. Recall that it requires about 29 days for the moon to orbit the earth. Consequently, during the 24 hours required for the rotation of the earth, the moon has changed its position slightly, and moved in its orbit beyond the position from which rotation started.

Elapsed time between two successive maximum high tides is approximately 24½ hours.

EXPERIMENT. Locate daily tide listings for a port city such as New York, Miami, Galveston, San Francisco, or Los Angeles. If such listings are not readily available, use the following data.

Low	*High*	*Low*	*High*
2:38 A.M.	8:56 A.M.	3:09 P.M.	10:32 P.M.
3:08 A.M.	9:30 A.M.	5:00 P.M.	11:34 P.M.
3:43 A.M.	10:11 A.M.	5:57 P.M.	12:56 A.M.
4:26 A.M.			

Make a large clock face on a piece of heavy cardboard. Show the time at which each tide occurs, indicating by H *or* L *the kind of tide. If you live near a coast, record the tides for one month. Otherwise, determine from the listings given the number of days for which you have data. How much time elapses between high tides? Compare the time elapsed from high tide to high tide over a full day for each of the above cycles. Why do the tides require more than 24 hours in their cycle? How does the elapsed time between high tides compare to the elapsed time between low tides?*

Figure 12-12.

12:5 *Shore Processes*

Tides, wind waves, and ocean currents cause ocean water to remain in motion. Waves carry water onto the shore, but water moved onto the shore returns to the sea. Along the shore, retreating water creates local currents which are not related to the major circulation pattern of the ocean.

Waves tend to wear away coastal materials. Boulders are broken off from rocky shores by the force of water dashed

Waves erode by the force of water dashing against the coast and by abrasion.

Phyllis G. Lewis

Figure 12-13. At Pismo Beach, California, waves have eroded soft rock and left a stack of resistant rock separated from shore.

against the coast. During storms, waves pound the shore zone with tremendous force. Before flowing back to sea, water may enter cracks and crevices and enlarge the openings into caves. Waves also have *abrasive* (a brae′siv) *action* as they roll rock fragments back and forth across the shore zone. Rock fragments are worn smaller and smaller in the shore zone and, eventually, the fragments may be carried away. Some solution also occurs, but abrasion causes most coastal destruction.

Flat, smooth *benches* are carved into rocky shores just below sea level. Above sea level, as high as storm waves reach, *notched cliffs* are cut into hard rock of the coast. Occasionally, *stacks* are left as isolated, upstanding blocks of rock which remain after less resistant (ri zis′tent) rock has been worn away.

Tidal scour deepens narrow channels.

Tides scour deep *gouges* (gauhj′es) in narrow channels. The velocity of the water is increased when the tide is confined to small, narrow openings. Both incoming and outgoing tides tend to deepen such channels in a process called *tidal scour*. This process is effective even in hard rock if sediments are available for abrasive action. Tidal scour cuts many channels in soft rock and in reef materials.

When tides and storm waves move in the same direction, surges of water pile up on shore and do great damage. During hurricanes, the water is prevented from returning to sea by the force of the onshore winds. Eventually, the water flows back to the ocean, carrying debris with it.

Figure 12-14. In the photo at near right, storm waves have undercut the cliff.

American Airlines

Figure 12-15. Here a notched cliff stands above the bench carved beneath the waves. Offshore a stack has escaped the forces of erosion.

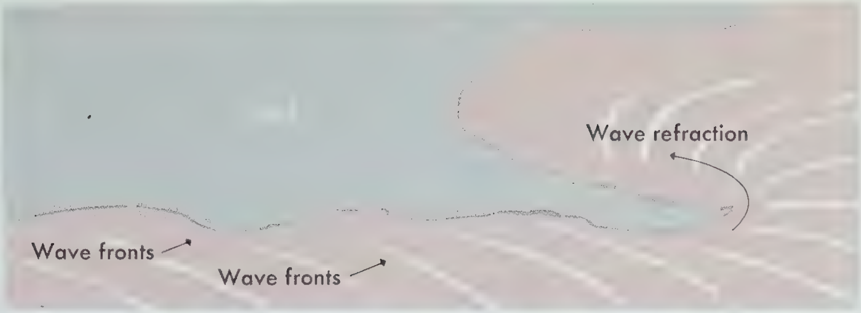


Figure 12-16. Waves approaching the shore at an angle are bent parallel to the coast line.

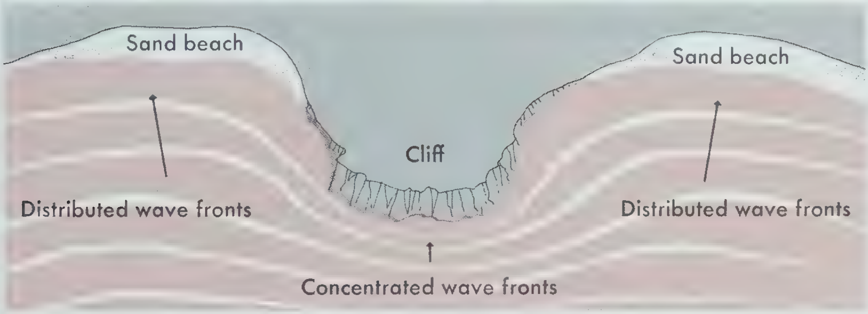


Figure 12-17. As headlands are eroded, they supply sediment for beaches in adjacent bays.

Along irregular coasts, wave energy is concentrated on headlands. *Headlands* are projections of land that extend into deep water. Waves wear headlands down faster than adjacent indentions or bays. Because waves tend to expend most of their energy on headlands, most wave energy is spent by the time they reach the bays. Some coasts have steep cliffs which are eroded slowly because waves strike the shore at an angle of 90°. Waves that strike a steep cliff head-on, are reflected toward the ocean and die out. Such waves cause little erosion along a shore. For this reason, vertical breakwaters are built along some shores. *Breakwaters*, like steep cliffs, reflect waves and protect the shore zone behind them. However, this type of protection is effective only along coasts where wind direction is relatively constant. If winds blow first from one direction, then from another, waves at some time strike breakwaters at an angle and erode them.

Headlands are eroded by waves that strike them at an angle.

Loose material eroded from headlands is deposited as beaches in adjacent bays.

Waves are bent, or *refracted* (ri frakt′ed), as they swing around headlands. The velocity of the waves decreases when they collide with the projection. In adjacent bays, waves continue to move forward with their original speed. Wave fronts resemble marching groups that swing around pivot men to turn a corner. No matter what their original direction, when waves reach shore they tend to align nearly parallel to it. However, even a small angle of reflection means that water returns to the sea some distance from where the wave carried it onshore.

Waves are refracted when a part of the wave reaches shallow water and is slowed down; the rest of the wave continues moving at its original velocity and catches up.

Waves may be reflected oceanward if they strike the shore at a 90° angle. Waves that strike the shore at an angle of less than 90° are deflected at an angle to the shore.

Gravity pulls water back down the shore slope toward the sea. Movement of water as it returns to the sea forms local currents known as **longshore currents.** Waves that strike the shore at an angle of 90° are reflected directly toward the sea. If waves meet the shore at some angle less than 90°, the water returns to the sea some distance from the place where it strikes the shore. Incoming waves interfere with the return of water to the sea, and turn the current aside. As a result of both reflection of the wave and interference by approaching waves, longshore currents flow downwind but almost parallel to the shore. (Figure 12–18.) Longshore currents increase in strength as headlands and projections are worn away. Eventually, currents cease to follow the indentations of the shore. Instead, they flow down the beach in the direction in which they started. When the longshore current reaches deep water at the mouth of an indentation, its velocity decreases, and debris carried by the current is dropped to the ocean floor.

Longshore currents transport sediment parallel to the shore in a downwind direction.

Because water is always pulled seaward by gravity, even longshore currents eventually move toward the open ocean. When the current finds a break in the wave front, it escapes seaward through the break and becomes a **rip current.** Rip currents are not a hazard on gently sloping shores. But they may be swift, dangerous currents if wave action is strong, or if the slope of the sea floor is steep, as it is along some parts of the California coast. Good swimmers should be able to escape from the rip current by swimming parallel to the shore. These narrow currents flow perpendicular to the shoreline. If a person swims across the rip current, he soon should be able to reach less dangerous waters.

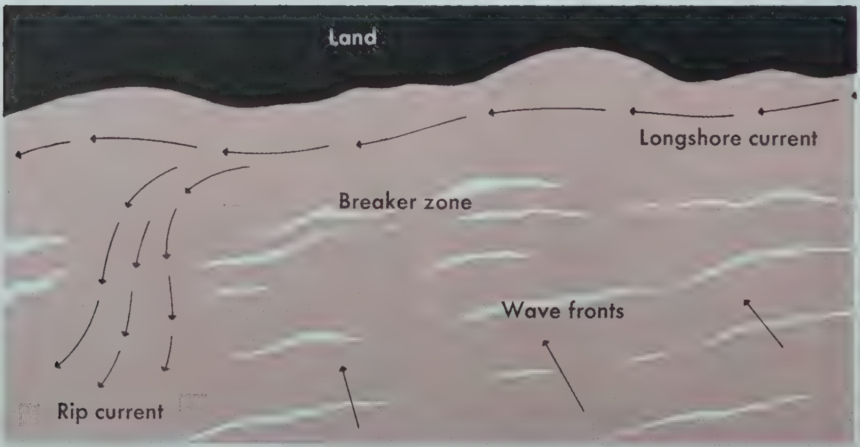


Figure 12-18. Rip currents carry water seaward as they break through an opening in the approaching wave front.

Not all water moves seaward as longshore currents or as rip currents. Some water moves seaward in a thin layer near the bottom. This movement is slow, but even a gentle **bottom current** moves sediment across the shelf toward the ocean basin. Dangerous surface currents are common around *jetties* (jet′ ees) and breakwaters where these artificial projections interfere with wave motion.

Some water returns seaward along the ocean bottom.

12:6 *Shore Deposits*

Coasts consisting of hard rock usually have steep cliffs. Coasts consisting of sand usually have gentle slopes toward the sea.

Steep cliffs commonly occur where hard rock is exposed along the coast. Around the base of the cliff, boulders eroded from the cliffs often form ridges or beaches. Shores that consist of sand have relatively gentle slopes because sand cannot withstand wave action or support itself on steep slopes.

Loose material along the shore zone is brought to the shore by rivers. Other debris is eroded from the coast by wave action. Waves and currents sort these shore materials according to size. Fragments too large to be carried are left in place. Smaller fragments are carried along the shore, onto the continental shelf, or even to the continental slope. Some of the finest particles reach the abyss. Weak waves remove little debris; strong waves and currents may remove and redeposit large quantities of sediment. Both the energy of the waves and currents and the amount of material in the shore zone determine what happens to the debris.

Beaches are deposits of loose material which are laid down parallel to the shore line. Beaches extend seaward to about 30 ft below mean tide level, and landward to the coastline. Much of the material in the upper part of the beach is kept in motion by waves.

Beach materials vary with the source rock.

Beach materials depend on the kind of rock which is exposed along the coast. If the rock is limestone, the beach will consist of lime fragments. Lime sand is often called "coral sand," although the material may not come from coral deposits. If basalt is exposed at the shore, beaches will consist of black sands or fragments of basalt. Some parts of the Oregon Coast and the Islands of Hawaii have black sand beaches. If waves erode granite or sandstone, the dominant beach material will be quartz grains, possibly with some feldspar. Most beaches in the United States are made of quartz sand grains. In the Bahama Islands, white beaches, often called "coral sand," are made of limestone.

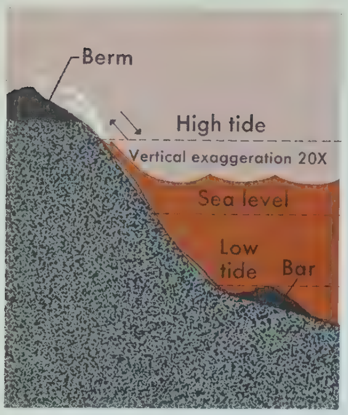


Figure 12-19. Storm waves leave a ridge of sand or gravel on the shore above the high tide level.

Recently formed beaches are usually narrow and shallow, and they form only a thin cover over the hard rocks below. Such beaches commonly consist of large boulders or gravel. New beaches often are swept away by winter storms, then rebuilt during the summer.

Beaches that have been exposed to the waves for a long time consist of fine sediments. In time, beaches become a permanent part of the shore, with a broad, deep berm. A **berm** is a ridge made of gravel or sand carried onto the shore during exceptional storms. It is the most familiar part of the beach, because the berm is above sea level. Berms are deposited above the shoreline by waves that splash over them continually. Waves keep the seaward slope of the berm gentle, but the back slope is steep because materials are pushed over the high point of the ridge and then roll down the landward slope. (Figure 12–19.)

Bars and spits are deposits of sand across a bay or indentation of the shore. *Spits* are deposits attached to the land at only one end. *Bars* are built completely across the mouth of a bay, and are attached to the mainland at both ends. Bars and spits are composed of material that is eroded from the headlands and carried into the bays by the longshore current. Debris is deposited at the head of a bay where the current flows into quiet water. During the development of a shore, headlands are worn

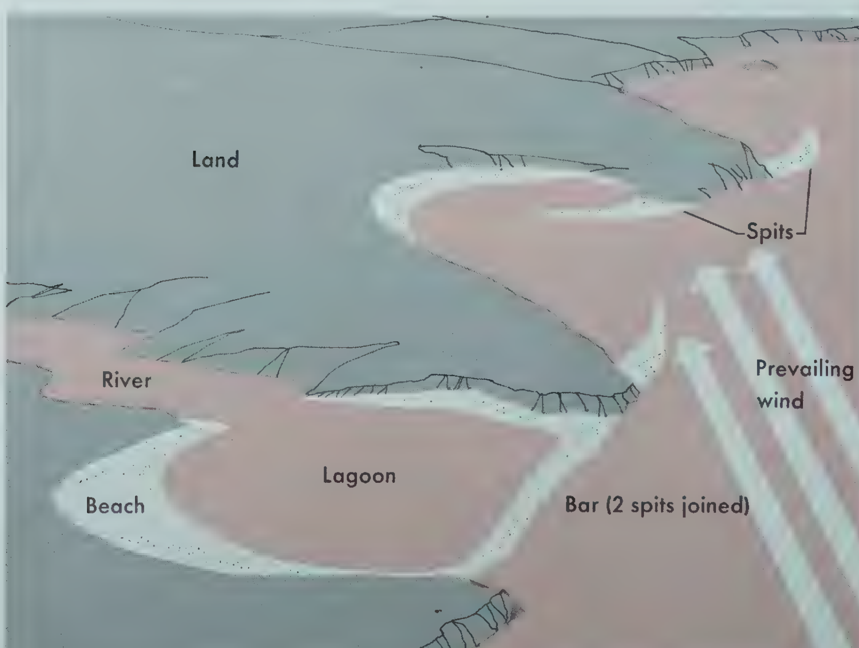


Figure 12-20. Longshore currents lose velocity and drop their load of sediment in the deeper water of the bays and indentations.

away and bays are cut off by bars and spits. In the early stages of development, when headlands are prominent, the longshore current sweeps into the bay and deposits beaches adjacent to the headland. Later in the history of the shoreline, bars and spits are deposited across the mouth of the bay, and the longshore current no longer enters the bay.

Bars and spits also may be built where rivers empty great quantities of sediment at the shore. Material is redistributed beyond the river mouth by the longshore current. Eventually, the river may be completely blocked by a bar. Water trapped behind the bar forms a lagoon which may become filled by river deposits or organic material, or which may be evaporated. If strong tidal currents are present, a connection with the sea may be maintained by the process of tidal scour.

Lagoons are bodies of water parallel to the shore and behind a bar or spit.

Barrier islands are offshore deposits of sand that form parallel to the shore. Barrier islands develop from sand ridges that are formed under water by breaking waves. Such ridges may form at various depths, depending on where the waves tend to break. Underwater ridges near shore are only about one foot below mean water level. Occasionally, hurricanes dump great quantities of sand on these ridges and raise them above sea level. Once exposed, sand from the ridge may be blown into

Barrier islands are deposits of sand lying seaward from the mainland and separate from it.

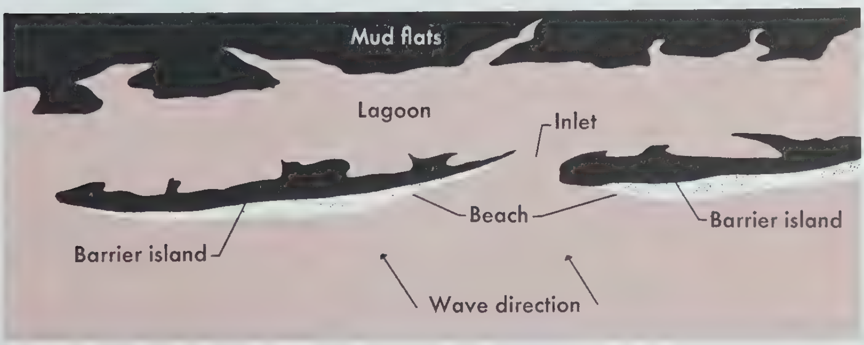


Figure 12-21. The mainland will be extended outward to the barrier island as mud continues to fill the lagoon.

dunes. Then the ridge becomes a true *island* and presents a new shore zone to the sea. The new shore zone is widened by the growth of a berm and the island is lengthened by the growth of spits.

Some underwater ridges may become barrier islands through a lowering of sea level. Both the Atlantic Coast and the Gulf Coast of North America have many barrier islands that extend for miles parallel to the shore but separated from

An **island** is a small tract of land surrounded by water.

the mainland. It is believed that these barrier islands formed during the changes of sea level associated with the advance and retreat of great ice sheets.

A **rill** is a minute stream of water, especially one that flows away from a beach as a wave subsides.

Both deposition and erosion may be observed along the seashore. The onrush of waves brings debris to the shore. This is followed by the slow return of the water, which forms little *rills* that branch out like trees whose trunks point landward. *Ripple marks* are formed as the wave pushes some sand toward the shore, and outgoing currents push the grains back toward the sea. Tiny ridges of sand are left behind as a result of the back and forth movement of the water. Some ripple marks are symmetrical (sa me′tri kal) ridges with similar slopes on both sides of the ridge. Some ripple marks are asymmetrical; that is, one slope is much steeper than the other. Asymmetrical ripple marks are like miniature sand dunes, and they may be formed by the wind or by currents that meet the shore at an angle.

Erosion and deposition constantly change the shore zone.

Erosion and deposition constitute a never-ending cycle. Waves smooth the shore by eroding the headlands. Currents smooth the shore by depositing bars and spits across indentations. Eventually, erosion and deposition should fashion a shore zone in which all headlands are worn away, all indentations are cut off, and cliffs are worn back so far inland that wave action is no longer effective. This ideal state of equilibrium never exists for long. Crustal movements, such as earthquakes, raise or lower portions of the coast. Glaciers creep over the land, and then melt, first lowering, then raising sea level. Any change in the position of sea level causes shore processes to begin their work again. Like the rock cycle and the hydrologic cycle, the *erosional cycle* has no end.

MAIN IDEAS

1. Major surface currents begin in the tropics and flow in great circles in each ocean and in each hemisphere. Currents are deflected to the west by the trade winds, north and south by continental barriers, east by the westerly winds, and south and north by other continental barriers.
2. Surface currents distribute heat along shores and carry nutrients from place to place.
3. Deep ocean currents move toward the equator and beneath the surface. These currents are cold and dense compared to surface currents.

4. Tides on the side of the earth facing the moon are due to the moon's gravitational attraction. On the far side of the earth, the centrifugal force is probably the major cause of tides.
5. Spring tides occur when the moon, earth, and sun are in line with each other. Neap tides result when the sun and moon are at right angles to each other.
6. Waves are rhythmic movements of water caused by the gravitational attraction of the moon, submarine vibrations, or by wind.
7. Wave base of deep water waves is above the ocean bottom. Shallow water waves form in water that is less deep than half of the wavelength.
8. Water carried onto the shore by waves returns to the ocean basin due to the pull of gravity.
9. Waves and currents carve rocky shores into notched cliffs, cut benches, isolated stacks, and caves. Boulders carved from the shore are ground smaller and smaller by abrasion, and eventually the loose material may be transported to another location.
10. Shore deposits include beaches, berms, bars, spits, and barrier islands.
11. Destruction and construction by waves and currents are never-ending processes.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

abrasive	refract
berm	resistant
crest	rip current
density current	spring tide
jetty	stack
longshore current	tidal scour
neap tide	tsunami
notched cliff	turbidity current
oscillatory wave	upwellings

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Rotation of the earth deflects ocean currents as well as air currents.
2. Channels formed by turbidity currents are related to rivers from the continents.
3. Tides are shallow water waves.
4. Spring tides take place in the spring, summer, fall, and winter.
5. Tsunami, sometimes called tidal waves, have no connection with tides.
6. Water particles are never carried forward onto the shore by oscillatory waves.
7. Beach sand is composed of quartz grains.
8. Spits are deposited by a longshore current.
9. Motion of the waves is greatest at wave base.
10. Wave size depends on the depth of water alone.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Currents flowing toward the equator beneath the surface are (*turbidity, density, longshore*) currents.
2. Wavelength is measured horizontally from (*crest to crest, crest to trough, trough to wave base*).
3. Wave height is measured vertically from (*crest to trough, trough to wave base, crest to crest*).
4. Sand deposits built across the mouths of indentations along the shore are called (*bars, spits, berms*).
5. Currents that flow parallel to the shore are called (*rip currents, density currents, longshore currents*).
6. Turbidity currents are dense due to (*suspended sediments, evaporation, freezing of surface sea ice*).
7. Shore zone deposits include (*turbidity sediments, coral sands, ooze*).

8. The gravitational attraction of the moon causes (*tsunami, rip currents, neap tides*).
9. Barrier islands are due to (*erosion by waves, deposition across bays, ridges formed by breaking waves*).
10. Spring tides are caused by (*gravitational attraction of moon and sun working together, gravitational attraction of moon and sun working in opposite directions, excess rainfall during the spring*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Two ocean currents in the Atlantic Ocean that follow the east coast of the American continents are the __?__ and the __?__.
2. Ocean tides are primarily the result of the gravitational attraction of the __?__.
3. New moon and full moon are associated with __?__ tides.
4. First-quarter and third-quarter moon positions are associated with __?__ tides.
5. Waves caused by submarine earthquakes are called __?__.
6. Shallow water waves occur in water that is half the __?__.
7. Ridges of sand that lie parallel to the shore but are separated from the mainland are called __?__.
8. Beaches in Hawaii and Oregon are black because they contain __?__ fragments.
9. Water pushed onto the shore by the waves becomes a __?__ current, flowing parallel to the shore before it returns to the deep ocean basin.
10. Currents flowing in and out of the Mediterranean Sea are __?__ currents.

D. How and Why

1. What conditions cause differences in the density of seawater? Suggest at least two reasons why water at the equator is less dense than water at other latitudes.

2. What conditions determine the size of wind waves? Suggest reasons why wind waves are never shallow-water waves in mid-ocean.
3. Explain why upwellings of cold water contain nutrients which may be lacking in warm surface water. What is the origin of upwellings and why do they sometimes fail to occur in the usual places?
4. Define abrasion and list several examples of abrasion. Discuss the process of abrasion along a shore. What is the source of the "tools" of abrasion in turbidity currents?
5. Why do shallow water waves erode the bottom of the ocean, but deep water waves do not?
6. During the 1964 Alaskan earthquake, Crescent City, California, was damaged by a huge wave. Was there any connection between these events? Explain your answer.
7. Why are tides higher in some places than in other places? For example, the Bay of Fundy has a 40 ft tide, whereas the Gulf of Mexico has a high tide about 2 ft above normal.
8. What two processes tend to smooth the shoreline?
9. Why do waves break only along the shore zone?
10. What evidence would indicate whether or not a shore zone had been uplifted?
11. What would happen to tides on the earth if there were no moon? What would happen to tides on the earth if the earth did not rotate? Explain your answers.

INVESTIGATIONS

1. On an outline map of the world, draw the major ocean currents. Compare them with the wind belts of the world. (Chapter 10.) Note any similarities or differences.
2. Discuss types of shorelines and ocean features using pictures or illustrations which you have drawn. Include wave action, notched cliffs, types of beaches, atolls and lagoons, barrier islands and reefs, stacks, benches, berms, spits, and bars.
3. On a map of the United States or of North America, locate barrier islands in the Atlantic Ocean and the Gulf of Mexico. Discuss why such islands are found in these localities but not on the west coast of the United States.

INTERESTING READING

Bascom, Willard, *Waves and Beaches.* New York: Doubleday & Company, Inc. 1964.

Coker, R., *This Great and Wide Sea.* Evanston, Ill.: Harper & Row Publishers, 1962.

Defant, Albert, *Ebb and Flow.* Ann Arbor, Michigan: The University of Michigan Press, 1958.

*Engle, Leonard, *The Sea.* Life Nature Library. New York: Time, Inc., 1961.

* Well-illustrated material.

The Earth's Crust Redesigned

...take into account the sudden changes, such as great volcanic eruptions, which must at different epochs have deranged the regularity of these changes.

Pierre Laplace (1749-1827)

The surface of the earth is being changed constantly, gradually by wind and water through weathering and erosion, and suddenly by violent adjustments of the crust.

James Hutton and Sir Charles Lyell, British geologists of the eighteenth and nineteenth centuries, agreed that they could see no sign of a beginning nor any prospect of an end in the slow processes of construction and destruction which gradually change the face of the earth. Hutton proposed, and Lyell supported, the proposition that earth features of any period are the result of processes which have been in operation during all of the past.

In time, weathering and erosion would reduce the earth to a level plain, if revolutions of the crust did not occur occasionally. Eruption of volcanoes, uplift of mountains, and fracturing by earthquakes upset the regularity of gradual changes. Old rivers become young as their plains are uplifted; old mountains lose their identity as they are leveled and eventually covered by the sea. Rivers change their courses; familiar islands disappear and new ones emerge during catastrophic upheavals.

Violent changes are dramatic and exciting, but geologists must observe patiently over long periods of time in order to understand and interpret the causes of sudden changes and the effect of slow leveling processes.

UNIT Four

13 Mass Movements and Running Water

Processes of destruction and construction, so obvious along shore zones, are constantly redesigning the lithosphere. Water and air act to weather materials of the crust, loosen and transport fragments, and finally consolidate them into new forms. Although these processes are slow, they are constant and would reduce the surface of the earth to sea level if neither crustal nor internal movements counterbalanced the removal of material. Look about you for signs of these processes at work.

13:1 *Erosion*

Weathered material is transported, deposited, and resolidified into new rock.

Recall that weathering is the change of rock material *in place*. (Section 6:2.) It is most effective on level ground in humid climates. Here vegetation holds the rock material until it has been disintegrated and decomposed by water and air.

Erosion is the process of wearing down the land surface. Rivers, wind, underground water, ocean waves and currents, and glaciers are agents of erosion.

Erosion (i roh′zhun) is the loosening and transporting of material by *moving* agents. It includes the work done by waves and currents as they tear down shorelines and transport debris to other locations. Percolating groundwater beneath the surface, slow-moving glaciers, and winds and currents of air also wear away the land. Most important is erosion done by running water in surface streams. Compared to streams and rivers, all other erosional agents are of minor importance.

Sometimes these forces work quietly and slowly for long periods. Often their work is dramatic and startling. Because sand dunes and glaciers inch along, their movement is almost unnoticed. Some rivers glide along their banks, but others rush in torrents which deepen their valleys rapidly and form deep canyons and *gorges* (gawrj′es). Groundwater works so silently that its action remains unnoticed until huge underground caverns are discovered. Sudden storms cause streams

Union Pacific Railroad Photo

Figure 13-1. A youthful stream plunging down a steep slope in Yellowstone Park forms one of the Park's famous waterfalls.

to carve channels in level land. Long periods of slow rainfall saturate loose soil and cause hillsides to slump and creep downward under the influence of gravity.

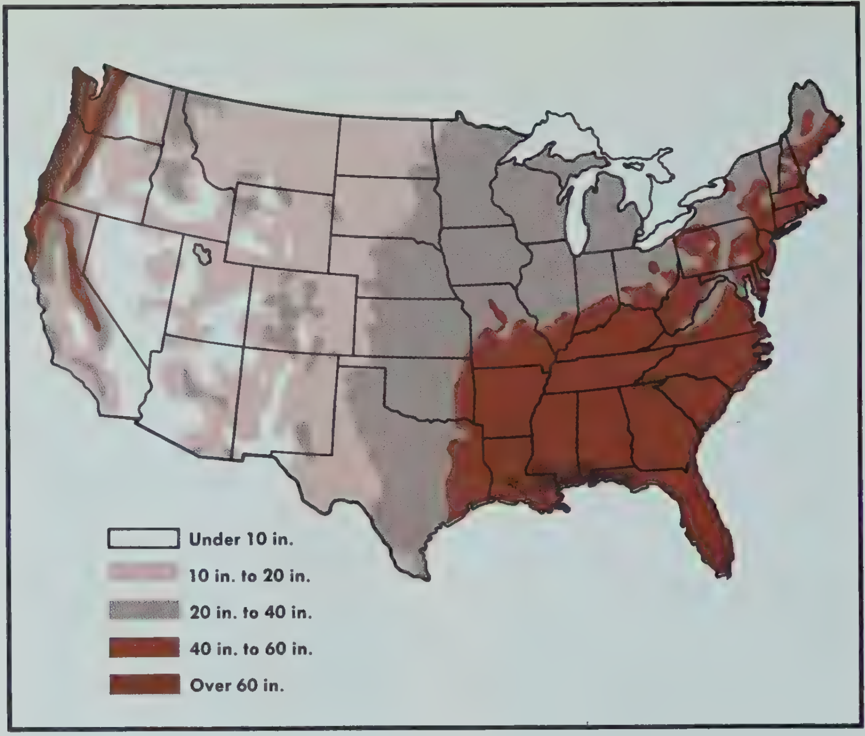
13:2 *Runoff*

Most of the water in the hydrologic cycle falls on the land surface as rain, snow, sleet, or hail. Some of this water evaporates into the air; some is used by animals and plants; some sinks into the ground, where it is held in the openings in rocks for a time. But nearly 40 percent of the water that falls on the land flows back to the sea by way of surface and underground streams. The water which flows on the surface in streams and rivers is called **runoff**, or running water.

Runoff is also water flowing across the surface of the land.

Several factors which affect runoff are the amount and type of rainfall, the slope, or *gradient* (graed′ee ent), of the area receiving the rainfall, the type of material over which the water flows, and the amount and kind of vegetation present.

Figure 13-2. Average annual rainfall in the United States ranges from 80 inches to less than 10 inches.



Relief is the variation in the height of earth's surface.

Rainfall depends on the amount of moisture carried by the winds, and upon the relief of the land. The United States has five rainfall zones from east to west. (Figure 13–2.) The Atlantic Coast receives about 40 in. of rainfall per year. About 30 in. of rain falls in the Mississippi River drainage basin. The Western Plains receive about 20 in. Between the Rocky Mountains and the Sierra Nevada, the Great Basin has about 10 in. of rain. The Pacific Coast receives between 40 in. and 80 in. of rain per year. These figures represent an average amount of rainfall for a period of at least 10 years.

In addition to the amount of rainfall, runoff is affected by many other factors. The *rate of precipitation* and the *temperature* influence the amount of runoff. Snow and gentle showers promote evaporation and absorption of moisture rather than runoff. However, torrential (taw ren′chal) rains cause rapid and violent runoff which results in severe erosion. Warm temperatures increase the rate of evaporation, but cold temperatures promote runoff. When temperatures are low enough for freezing, precipitation may become trapped as ice or snow. Then, when thawing occurs, runoff will be slow or rapid, depending upon the rate of melting.

Gradient is an important factor in determining the amount and rate of runoff. Steep slopes shed rain quickly before it can

be absorbed by the ground. Gentle slopes and plains retain water temporarily, but eventually lose it to the underlying groundwater zone.

The *type of rock* on which the rain falls also influences the amount of runoff. Porous rocks allow water to sink into the ground. Loose material may become saturated with water. On hillsides, sheets of saturated soil often creep slowly toward the valley. Steep hillsides made of loose particles show the most destructive effect of runoff. Here raindrops form rills, rills become gullies (gul′ees), and gullies deepen rapidly into ravines. Coarse, rocky material has little effect on slowing the flow of water downslope.

Runoff is rapid on steep slopes and slow on plains.

Vegetation also determines whether runoff or absorption occurs. Ground that is covered by trees, grass, or shrubs has little runoff. Streams flowing through forest areas are usually clear because little soil is suspended in them and carried away. Such streams have a fairly constant rate of flow because movement of water into the streams is gradual.

Vegetation cover retards runoff.

USDA Photo

Figure 13-3. Torrential rainstorms form gullies in soft, unconsolidated soil.

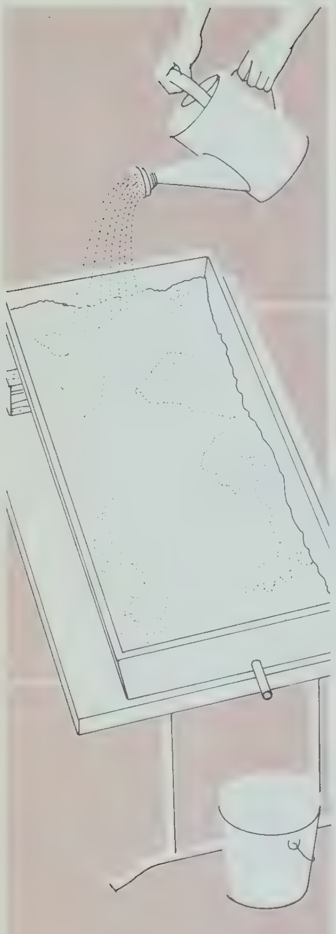


Figure 13-4.

EXPERIMENT. *Prepare a stream table from a rubber or plastic tub, or from a wooden nursery flat about 3 ft x 2 ft x 4in. Waterproof the wooden box with caulking compound. Make an opening at one end of the tub or box equal to the diameter of a piece of rubber tubing. Insert the tubing and seal the joint. Pack sand in the stream table to a depth of 2 in. If the sand contains clay, be sure to wash out the clay, or it will clog the outlet from the stream table. Create some surface features with the gravel and sand. With wooden blocks or books, raise the end of the stream table opposite the outlet. Put a container below the outlet to catch the runoff.*

Fill a sprinkling can with water. Sprinkle the surface at the raised end of the stream table. Vary the rate of rainfall and observe the patterns that develop. Is the pattern dendritic *(den-drit'ik), similar to the branches of a tree, or does the pattern have sharp bends? Is this the most common stream pattern? To answer this question, examine topographic maps of the United States.*

In the stream table, how does the rate of rainfall affect the depth of the stream channel? How does the location of gravel affect the stream flow? What force causes the water to flow down the slope?

EXPERIMENT. *Using the same stream table, observe the effect of a change in slope on stream velocity. It is necessary to maintain a constant rate of flow so that the slope is the only variable. Arrange the stream table so that you can place a container of water at a higher elevation. (Figure 13–5.) Use a piece of tubing to siphon the water from the container to the river system in the stream table.*

Now increase the height of the high end of the stream table. What changes in pattern and velocity occur? Raise the outlet end of the stream table. What is the effect of this change in slope? Note: Keep the stream table for future experiments.

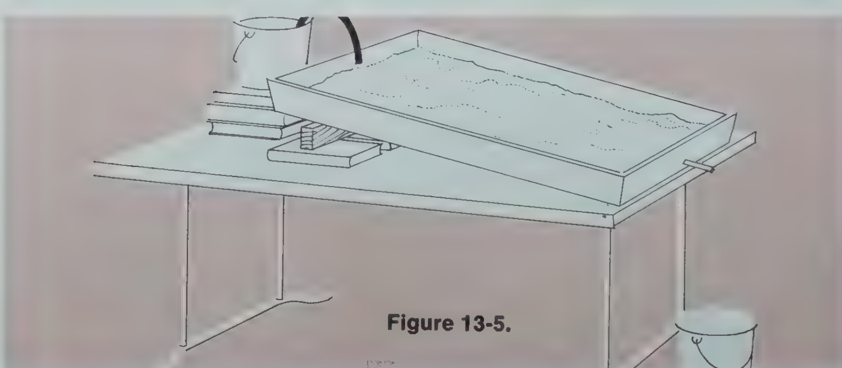


Figure 13-5.

PROBLEMS

1. If the stream table is 3 ft long and it is raised 6 in. above the table, what is its gradient? What is the gradient if one end of the stream table is 1 ft above the table?
2. What changes in stream pattern and velocity follow an increased gradient? What changes in stream pattern and velocity follow a decreased gradient?
3. What are two variables that influence the amount of erosion done by a stream?
4. Using only the materials required for the preceding experiments, discover another variable that determines how rapidly the stream can cut down its bed.

13:3 *Erosion in Arid and Humid Climates*

Comparison of the erosional effects of running water in arid (ar′ id) and humid climates shows clearly the importance of factors which influence runoff. *Arid regions* usually have less than 10 in. of annual rainfall, which is insufficient to support much vegetation. In arid regions, evaporation greatly exceeds rainfall. *Semiarid regions* have approximately 15 in. to 20 in. of rainfall per year, which supports only short grasses. In *humid regions*, rainfall ranges up to 80 in. per year, and exceeds both evaporation and transpiration.

In arid or semiarid regions, little vegetation is present. Although rainfall occurs only occasionally or intermittently, it is usually violent. Under these conditions, runoff causes widespread erosion. The effects are especially striking in soft clay or sand. Ridges become more pronounced and gullies deepen with every rain. The Badlands of South Dakota is an excellent example of this type of *topography* (ta pahg′ ra fee), or features of a landscape.

In areas where both weak rock and resistant rock are present at the surface, soft or soluble rock may be carried away, leaving masses of resistant rock. Steep-sided, bare rocky remnants of various sizes often rise abruptly from desert plains. These remnants of erosion are called *inselbergs* (in′sel burgs). (Figure 13–8.) On dry level land, erosion is less rapid than on steep slopes. Nevertheless, large masses of rock may be worn away, leaving high erosional remnants between the valleys. *Buttes* (beuts) may remain as streams cut deeper and deeper into a region. In the Southwest, masses capped by hard, resistant

American Airlines

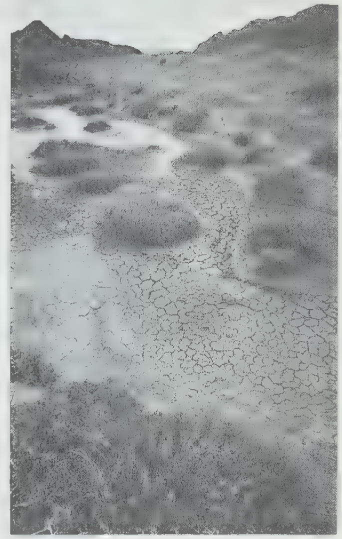


Figure 13-6. Mud cracks in the channel of an intermittent stream during the dry season.

Figure 13-7. This isolated hill or butte is surrounded by the eroded edges of upturned sedimentary beds.

N. H. Darton, U.S. Geological Survey

Figure 13-8. Inselbergs surrounded by talus slopes rise abruptly from the desert sands.

Santa Fe Railway Photo by Don Erb

Buttes and mesas have identical rock layers. Buttes are smaller with a narrower top than the broad-topped mesas.

layers of lava, limestone, or sandstone form flat-topped table lands, or *mesas* (mae′sas), the Spanish word for tables. The resistant layer protects the soft layers beneath it from erosion. The height of a mesa is a measure of the thickness of material that has been removed by erosion of valleys around the mesa.

Erosion is most complete in humid regions if river systems have had sufficient periods of time to develop.

In humid areas, erosion caused by runoff is less dramatic, but probably more effective, than in arid country. Rainfall is seldom violent, but it is frequent. Usually enough vegetation covers the surface to retard the flow of water and to allow time for the formation of a network of streams. Slopes, even if they are steep, are often wooded. Surface materials usually have had an opportunity to become weathered. Under these conditions, small rills tend to flow together to form gullies, gullies become brooks, brooks join to form streams, and streams form a complex network called a **river system**.

Figure 13-9. This cross section shows the development of alluvial fans along the mountain front. Only inselbergs extend above the sediments.

13:4 *Humid River Systems*

Development of a river system depends upon the force of gravity. In humid regions, gravity causes runoff to flow to lower and lower levels until, eventually, it reaches the sea. A typical river system begins in mountains, gathers speed as it reaches the lower hilly country, and finally emerges on the plains, across which it flows steadily toward the ocean. From mountains to plains, gradient lessens but volume increases. Velocity is dependent upon both gradient and volume. Little mountain streams seem to bubble along at a rapid rate, but their velocity is actually less because they lack the volume of the mature stream. For a given volume of water, the steeper the slope over which water flows, the more rapid is its velocity. In the early stages of stream development, gradient is the important cause of rapid flow. Later, when the stream has a greater volume, it flows rapidly in spite of its reduced gradient. Streams have their greatest volume and swiftest velocity during spring floods.

Humid climate drainage systems often are described in terms of youth, maturity, and old age. However, the *age of a river* does not refer to its age in years, but to the amount of work remaining to be accomplished in reducing the region to sea level. Billions of tons of debris must be removed from a mountainous region, or even from an inland prairie that is thousands of feet above sea level. On the other hand, rivers flowing through coastal plains have few youthful characteristics, because the land is already close to sea level. Because age refers to the amount of erosion yet remaining to reduce a land to sea level, a stream flowing over resistant rock remains youthful much longer than one flowing through regions of soft, loose material. Also, those parts of a drainage system that are closest to the sea are older than the parts higher up in the mountains.

In youth, rivers flow rapidly through narrow, straight V-shaped valleys.

Youth of a river begins when runoff is directed toward a definite channel after each rainfall. Water always flows toward any natural depression in the land surface. Here water may remain in a puddle, or even in a lake if the depression is large. However, when the depression is full and water overflows, the water moves downward to lower levels. Usually it follows the shortest distance, but if resistant material is present, it follows the easiest path. The water flows around the obstruction and goes through soft material. Runoff continues to

Figure 13-10. River valleys widen as a stream approaches old age. However, the river channel occupies only a smaller portion of the valley.

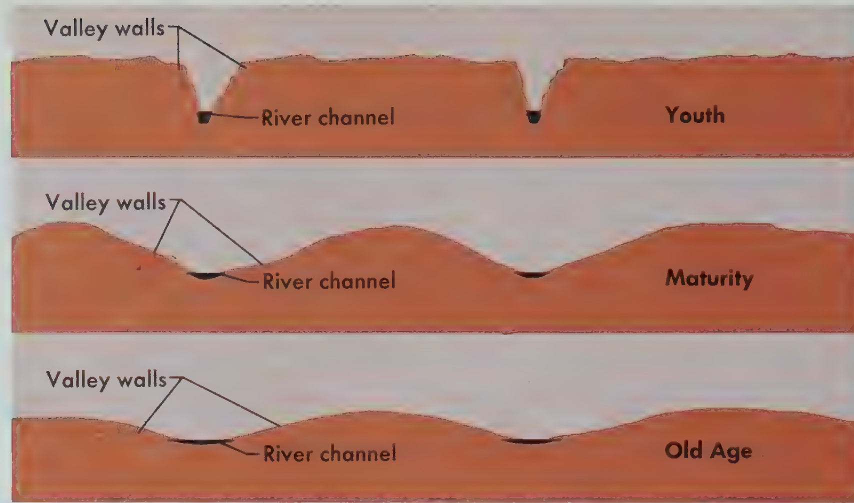
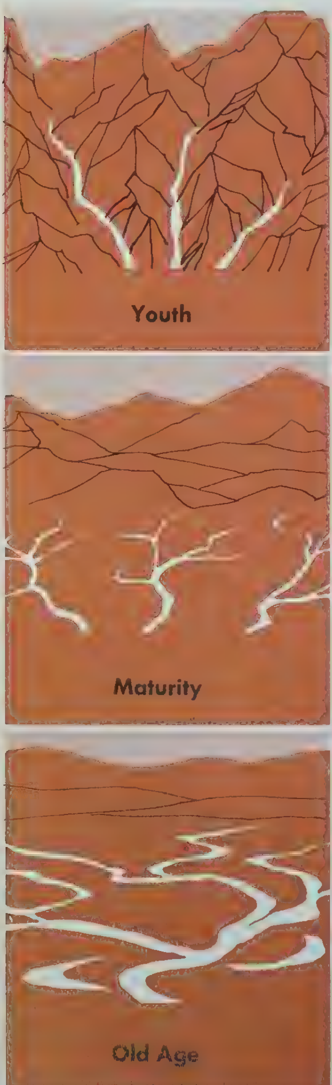


Figure 13-11. Drainage patterns become increasingly complex as a stream develops.



follow the same path after every rainfall, and eventually the connections between depressions become channels, and a river is born.

During the youthful stage, channels are short and relatively straight. Valleys are V-shaped and just wide enough to hold the available water. In early youth, a stream may flow swiftly, but it has little material in suspension with which to erode its channel. As the river flows onward, it picks up more and more fragments from the sides and bottom of the channel. Particles of silt and sand serve as tools with which the stream *abrades*, or grinds off, rocks from the stream channel. Fragments are carried upward and downward with the river currents. As the particles strike the sides and bottom of the stream channel, they wear away the rock in the same way that wood is smoothed by rubbing it with sandpaper. At the same time, the particles themselves become rounded. By examining the shapes and sizes of the fragments, geologists often can judge the distance that the fragments have been carried.

Youthful streams erode their beds downward, using particles carried within the stream itself, as well as material that is rolled along the bottom of the channel. These particles constitute the *stream load*. The amount of material that a stream can carry depends upon its velocity. In youth, a stream usually can carry a larger load if the material is available. As a stream develops from late youth into early maturity, its load begins to equal its capacity to carry materials. Then, if its velocity is decreased, the stream deposits some of its suspended material.

Maturity of a river is reached when the river has reduced its slope until its velocity is just great enough to carry its load. By

this time, the river channel is well established. Downward erosion is almost complete, and the stream is cutting sideward and widening its valley. The river gradient is so slight that any irregularities, such as resistant rocks, fallen trees, slumps of material from the valley walls, or depressions below the normal channel level, cause the water to swing from side to side in the channel. As the water travels sideward it develops S-shaped curves called *meanders* (mee an′ders). A meandering stream (Figure 13–13) cuts on the outside of the curves where velocity is swift, and deposits on the inside of the curves, where velocity is reduced. The river channel gradually is moved back and forth over a wide area, called the *river valley*. By maturity, a river system has developed tributaries. *Tributaries* (trib′ye ter ees) are small streams which flow into larger streams. A mature river together with its tributaries forms a complicated network of streams that drain a vast region called a *drainage basin*. As maturity approaches old age, the region between streams is worn down closer and closer to sea level.

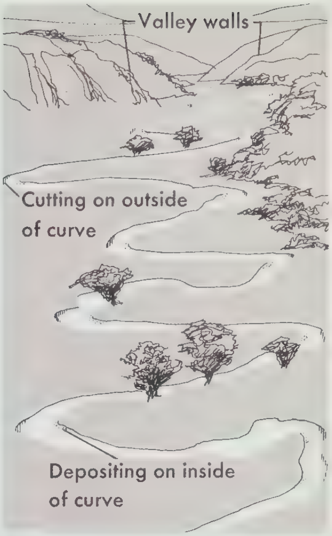


Figure 13-12. A stream erodes sideward as it meanders.

Figure 13-13. This meandering stream has widened its valley through sideward erosion.

W. T. Lee, U.S. Geological Survey

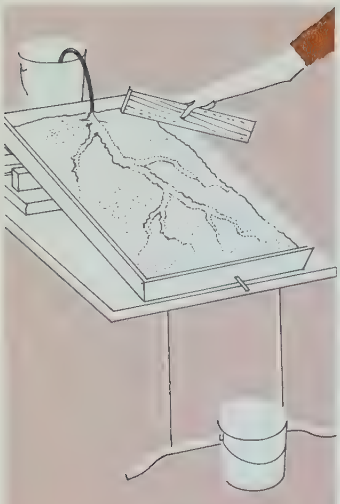


Figure 13-14.

EXPERIMENT. Use gravel or a piece of wood or plastic to build a dam across the stream in the stream table used in Section 13:2. Describe the stream both above and below the dam in terms of its velocity, its ability to transport materials, and its volume. Is the erosional ability of the stream changed?

Do dams increase or decrease the danger of floods? To answer this question, rapidly pour water into the stream table above the dam until water spills over the dam. Then, while still pouring the flood waters, make a diversion channel around the dam.

A river system reaches **old age** when its highlands are worn down nearly to sea level, and the river flows within a channel that makes up a small part of a wide valley. (Figure 13–10.) Resistant rocks, called *monadnocks* (ma nad′nahks), are the high land forms on a wide, eroded plain. *Oxbow lakes* are formed where the river cuts across its meanders and leaves arc-shaped bodies of water isolated from the main stream.

Crustal movement may rejuvenate an old stream and renew its erosional ability.

Rejuvenation (ri joova nae′shun) may occur when shifts in the elevation of the crust change the stream gradient. If an uplift of land occurs near the headwaters of a stream, the gradient is increased and the stream starts cutting downward again. Then the stream develops a V-shaped channel within its old meanders. Flood plains are left at an upper level in the form of *terraces* as the stream cuts downward. Such a stream is said to be rejuvenated, or made young again.

Paul W. Nesbit

Figure 13-15. Uplift of the land has caused this stream to erode its channel downward, forming a steep V-shaped valley within its meanders.

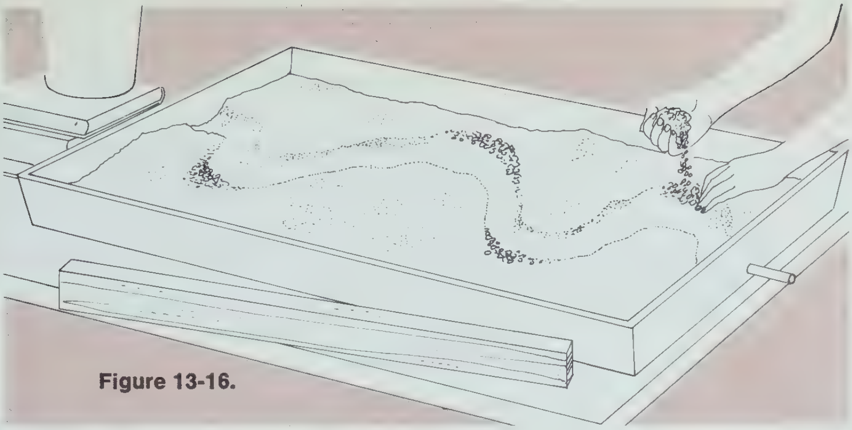


Figure 13-16.

EXPERIMENT. If the stream in the stream table has not developed some curves, fashion them in the sand and line a few of the banks with gravel. Adjust the gradient of the stream table or the velocity of the stream so that the water is moving just rapidly enough to move around the gravel. In which stage is this river system? Is it doing any erosional work?

Union Pacific Railroad Photo

Figure 13-17. Streams flowing in old glaciated valleys often become overloaded and form a braided pattern as they drop sediment within their channels.

13:5 River Deposits

Much of the material eroded by rivers is redeposited before the river reaches the sea.

Deposition occurs whenever the velocity of a stream is decreased below its capacity to carry its load of sediment. Few youthful streams are loaded to capacity and, consequently, youthful streams seldom deposit sediment except at the foot of an abrupt slope. Mature streams, however, transport sediment to the limit of their energy. Even slight reductions in velocity cause mature streams to deposit sediment.

Rivers remove approximately one foot of surface debris from the continents in 9,000 years. But only one-fourth of this sediment reaches the sea. The rest is redeposited locally within depressions of the drainage basins. Some material may be left within the stream channel itself, some may be deposited along the sides, and some may be dropped at the mouth of the river.

Every time the velocity of a loaded stream is decreased, some material is dropped. The flood plains built by mature rivers adjacent to their channels are familiar examples of deposition. When water pours into the stream channel in greater quantities than the channel can hold, some water spills over the sides. The velocity of the spilled water is reduced and deposition begins. The coarsest materials are dropped close to the river banks, forming mounds called natural *levees* (lev′ees). Beyond the levees are *alluvial* (a loo′vee ul) *plains* made of fine mud which settles from the standing flood waters. These plains are swampy

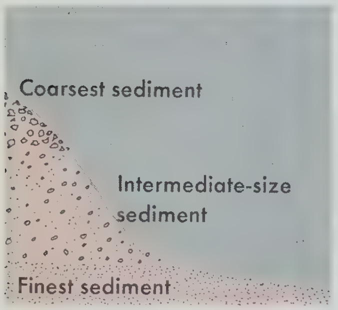
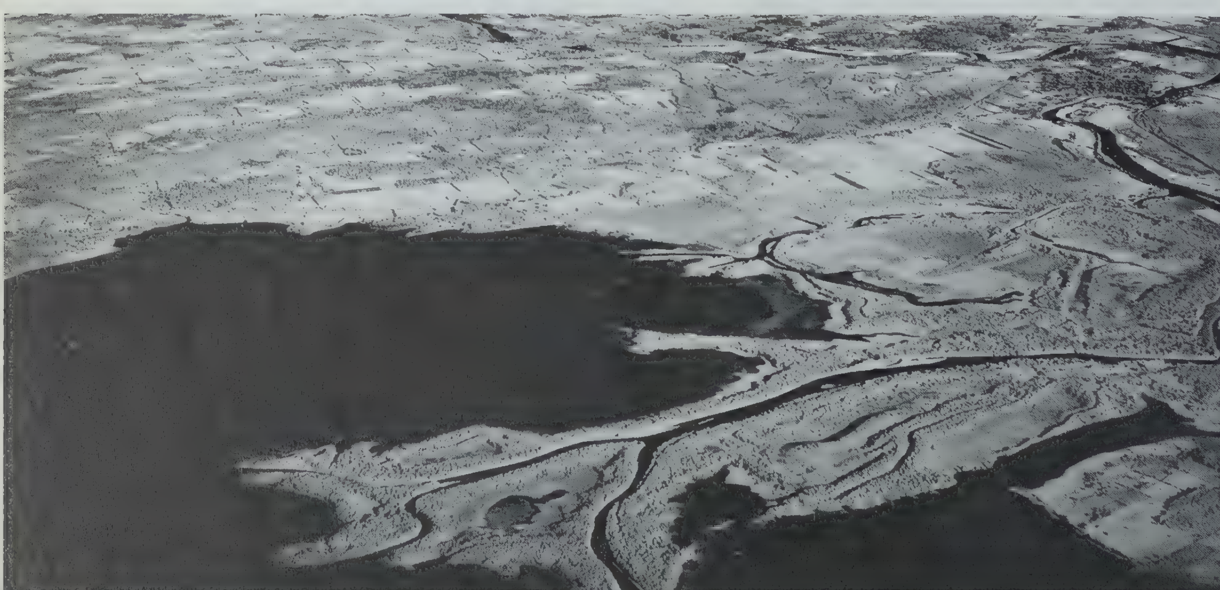


Figure 13-18. As a delta builds outward, coarse layers are laid down over fine sediments.

Figure 13-19. The Missisquoi River is building a delta at its mouth where it flows into a quiet lake.



and covered with excellent soil. In Egypt, most of the land available for cultivation comes from the yearly flood deposits of the Nile River. In the Mississippi River Valley, flooding adds a layer of fine rich soil to produce good farmland.

Levees and alluvial plains are deposited by both mature and old rivers during flood periods.

Another example of sediment deposition by rivers is the *delta* (del′ta). The shape of the Greek capital letter delta (Δ) gives rise to the term delta for the triangular deposits at the mouth of a river. When the stream enters a quiet body of water, its velocity is decreased, sediment is dropped, and new land is formed. Coarse material is dropped first, fine silt is carried a little farther, and mud is spread out a greater distance into the quiet water. (Figure 13–19.)

Deltas are formed where rivers flow into quiet, standing water.

In mountainous areas, streams form *alluvial cones*, or fan-shaped deposits, when they drop their loads quickly at the foot of a mountain slope. Abrupt changes in slope cause rapid decreases in velocity, and sorting is not as complete as it is in a delta. However, gravels are dropped nearest to the mountains, and fine silts and mud are deposited farthest away. Cones are common deposits along mountain fronts in arid regions. Often the cones spread out and join along the mountain front to form a continuous deposit called a *bajada* (bah hah′dah). (Figure 13–20.) Fine sediments are carried into the shallow, central basin between mountains. Since these desert basins, called *playas* (plie′as), are undrained, the water evaporates and deposits silt and sand in place.

Alluvial cones or fans of unsorted material are deposited at the foot of steep slopes in arid or semiarid regions.

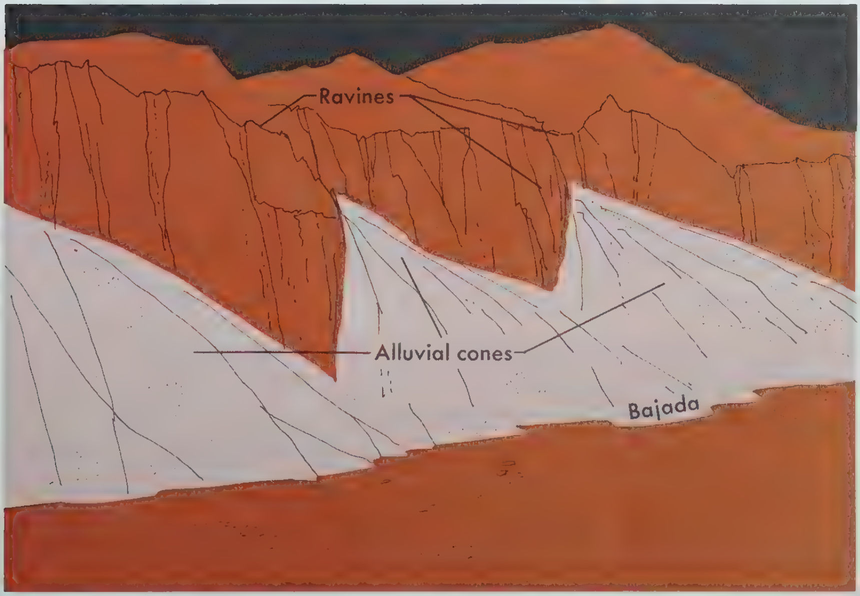


Figure 13-20. Loose material eroded from the mountain slopes forms alluvial cones at the mouths of the ravines through which the water flows.

13:6 Mass Movements

Masses of rock, ranging in size from particles which are barely visible to huge boulders, are loosened by weathering. When steep slopes become saturated with water, rock masses move down the slope in response to the force of gravity. The rock masses may slide as a thin sheet. This movement is called *creep*. Also, the rock masses may move as a rapid avalanche (av′a lanch), or landslide.

Creep occurs in humid climates where vegetation prevents rapid runoff and the soil becomes saturated. Apparently, clay swells with moisture and it becomes more subject to the pull of gravity. Fence posts, telephone poles, and trees that tip away from the vertical on hillsides are evidence that soil creep has taken place.

National Park Service Photo by Jack E. Boucher

Figure 13-21. Spring rains helped to lubricate loose material on the steep slope causing a dangerous landslide on this mountain road.

In humid areas, soil creep and landslides result when material on steep slopes becomes saturated with water.

Avalanches, or *landslides*, are rapid movements of large masses of loosened material. Landslides usually are started by earthquake vibrations. But on steep mountains, such as the Andes or the Alps, the spring thaw may initiate a landslide. Most landslides are small, but several large ones have caused great destruction. Much of the devastation accompanying the Alaskan earthquake of 1964 was due to landslides.

In arid regions, torrential rains bring down piles of weathered fragments that form heaps of debris at the foot of a slope. These *talus* (tae′lus) *slopes* consist of unsorted fragments and may contain huge boulders as well as small bits of rock.

Talus is the pile of loose rock that accumulates at the foot of a steep slope due to gravity.

In Arctic regions, freezing and thawing of surface rock creates a loose rock mantle of many different-sized fragments. The surface thaws in the spring, but the ground below the upper few feet remains frozen, and water cannot drain downward. Immediately after the spring thaw, a mass movement of rock debris starts downslope due to the pull of gravity. The mass moves slowly on the gentle slopes and swiftly on the steep slopes. Material may move as a single unit, or it may join other units in a jumbled massive flow.

Runoff and downslope movements are the major agents of land erosion. Together, these two agents cover more area and work longer than all other erosional agents combined.

Most erosion of the earth's surface is caused by runoff aided by downslope movements.

MAIN IDEAS

1. Weathering breaks down materials at the earth's surface; erosion transports and redeposits weathered material by means of runoff, underground water, glaciers, and wind.
2. Erosion by runoff depends upon the amount and type of rainfall and the surface on which the rain falls.
3. In arid climates, runoff is usually rapid and destructive.
4. Inselbergs, buttes, and mesas are erosional remnants of resistant rock found in arid and semiarid climates.
5. In humid climates, erosion is most complete as river systems develop from maturity to old age.
6. Rivers are called young when much erosion remains to be done to reduce the land to sea level. During youth, rivers deepen their channels. During maturity and old age, rivers widen their valleys and reduce the area between streams to near sea level.
7. When streams have reduced most of the slopes of their drainage basin and are following a winding course, they are called mature.
8. In old age, rivers flow slowly through plains which are reduced nearly to sea level. The plains have occasional remnants called monadnocks.

9. Rivers in maturity or old age may be rejuvenated and start down-cutting again following an increase in gradient or an increase in volume.
10. Depositional features of rivers include alluvial plains, levees, deltas, and alluvial cones.
11. Soil creep, landslides, and accumulations of talus result from mass movements of rock and soil on steep slopes.
12. Runoff and downslope movements are the two most effective erosional agents.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

alluvial	dendritic	inselberg	rejuvenate
arid	erosion	levee	talus
avalanche	gorge	meander	topography
butte	gradient	mesa	torrential
delta	gully	monadnock	tributary

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Erosion is a process which requires moving agents to accomplish its work.
2. Rainfall in the United States ranges from 10 in. to 80 in. per year.
3. Youthful streams are characteristic of mountains.
4. Clear streams are most likely to be found in level forest lands.
5. Rainfall accomplishes more erosion in arid regions than in humid regions.
6. The development of a river system is due to the pull of gravity.
7. Rejuvenation of a stream may cause a mature stream to regain certain characteristics of its youthful stage.

8. As a stream loses velocity, it deposits dissolved material.
9. Levees may be formed by rivers or built by man.
10. Deltas, alluvial fans, and talus slopes are deposits formed where a river flows into the ocean.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Erosion is most rapid on (*level plains, steep slopes, gentle slopes*).
2. The zone in the United States which receives the greatest amount of rainfall is the (*Mississippi River Valley, Atlantic Coast, Pacific Coast*).
3. Rejuvenation accompanies uplift of the headwaters of a stream because there is an increase in the stream's (*velocity, volume, suspended load*).
4. A V-shaped channel is typical of the (*mature, young, old*) stream.
5. High, flat-topped hills in arid country are called (*inselbergs, mesas, alluvial cones*).
6. Erosion is most effective if a stream carries (*no, suspended, dissolved*) material.
7. A drainage basin is established by a river in its (*youth, maturity, old age*).
8. Monadnocks and oxbow lakes are characteristics of (*youth, maturity, old age*).
9. The flood plain of a rejuvenated stream is (*above, at the same level as, below*) the stream channel.
10. Away from the river mouth, sediment in a delta is deposited in this order: (*silt, mud, sand; sand, silt, mud; mud, silt, sand*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Gullies are features of the __?__ stage of a river system.
2. Much of the rain which falls on gentle slopes and plains joins the __?__ rather than the runoff.

3. Four agents of erosion are ___?___, ___?___, ___?___, and ___?___.
4. Factors which influence the effectiveness of erosion are ___?___, ___?___, ___?___, and ___?___.
5. Rainfall in arid and semiarid climates is likely to be ___?___ and ___?___.
6. Meanders are not likely to appear until a stream reaches the stage of ___?___.
7. When meanders are cut off from the river, they form ___?___.
8. A meandering stream cuts on the ___?___ and deposits on the ___?___ of the curves.
9. Features constructed by mature rivers include ___?___, ___?___, and ___?___.
10. Downslope movements may be ___?___ or ___?___ depending on the speed of movement.

D. How and Why

1. In a humid climate, would surface materials of sand or clay favor runoff? Why? (Assume that the two materials have the same slope.)
2. Would you expect to find the least runoff in the uncultivated prairies of central Kansas, or in the desert of the Southwest, or in the heavily forested areas of the Pacific Coast? Why?
3. In what stage of development would a stream flow in a deep V-shaped, relatively straight channel?
4. Along the Mississippi River, where would you expect to find oxbow lakes?
5. Does construction counterbalance destruction in a drainage basin? Explain your answer.
6. Does flooding occur in desert regions, or only in humid climates?
7. Would flooding along the Rio Grande River of Texas enrich the soil as flooding along the Nile River and the Mississippi River does?
8. Stream gradients are usually steepest during early youth. Why are these streams less effective erosional agents than mature streams?

9. Why does the elevation of the playa region tend to rise in arid regions, but the elevation of the drainage basin in humid regions is continually lowered?
10. Discuss the permeability of granite compared to sandstone, conglomerate compared to shale, and coral sands compared to clay. (Refer to Chapter 5 and Chapter 6.) Which of these rocks would encourage runoff, and which would favor seepage into the ground?

INVESTIGATIONS

1. On an outline map of the United States, indicate the five rainfall zones.
2. On an outline map of the United States, show the Colorado River system. Indicate the humid and arid regions through which the river passes. Include all large dams and storage lakes and the Grand Canyon area. In what areas are new dams proposed or being built?
3. On an outline map of the United States, trace the entire Mississippi River system and the Missouri River system. Indicate areas of youth, maturity, and old age. Do you think a mistake was made in naming the system? Explain your answer.
4. Look for examples and pictures of soil creep as shown by tipping fence posts, telephone poles, trees, and houses. Discuss the causes and remedies.

INTERESTING READING

Jauss, Anne Marie, *The River's Journey.* Philadelphia: J. B. Lippincott Company, 1957.

Kuenen, Philip H., *Realms of Water; Some Aspects of Its Cycle in Nature.* New York: John Wiley & Sons, Inc., 1955.

Leopold, Luna B., and Langbein, W. B., *A Primer on Water.* Washington, D. C.: U. S. Government Printing Office, 1960.

*Leopold, L., and Davis, K., *Water.* Life Science Library. New York: Time, Inc., 1966.

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* Well-illustrated material.

Underground Water

Rainfall which sinks into the ground is known as underground water. Although the erosional effects of underground water are not as easily recognized as the erosional effects of runoff, underground water causes many important changes in the appearance of the landscape.

Some underground water is used by plants, some is evaporated, and some is stored in rocks. But most of the water that sinks underground eventually returns to the surface and joins the river systems.

14:1 *Zones*

Percolate means to pass or seep through permeable rocks.

Water percolates downward through underground cracks and through spaces between rock or mineral grains, until it reaches a layer of rock with no openings. At this depth, water begins to gather in the rock openings in the same way that water fills a glass.

Weathering occurs in the zone of aeration where air is present in rock openings.

The upper rock zone through which water can trickle easily is called the **zone of aeration** (aer ae′shun), or the *zone of oxidation*. In this zone, rock openings are filled with air, except immediately after a rain. This rainwater does not remain in the upper zone, but continues downward, allowing air to return to fill the openings. The presence of air gives the zone the name aeration. But the zone also is known as the zone of oxidation because oxygen and water react with elements in the rock to form new compounds. Most of the new compounds are combinations of oxygen and another element. They also may be combinations of carbon dioxide—another constituent of air—and an element. Recall that similar processes of decomposition occur on the surface. (Section 6:4.)

At the bottom of the zone of aeration, some water is held in tiny tube-like openings in the rock by **capillary** (kap′e ler ee) **attraction**. A *capillary* is a fine, hair-like tube which is capable of holding liquids because of the attraction between molecules of a liquid and a solid. Water is held in the small openings between rock grains in much the same way because of the attraction of the rock for the water.

Capillary attraction holds some underground water in the soil near the surface.

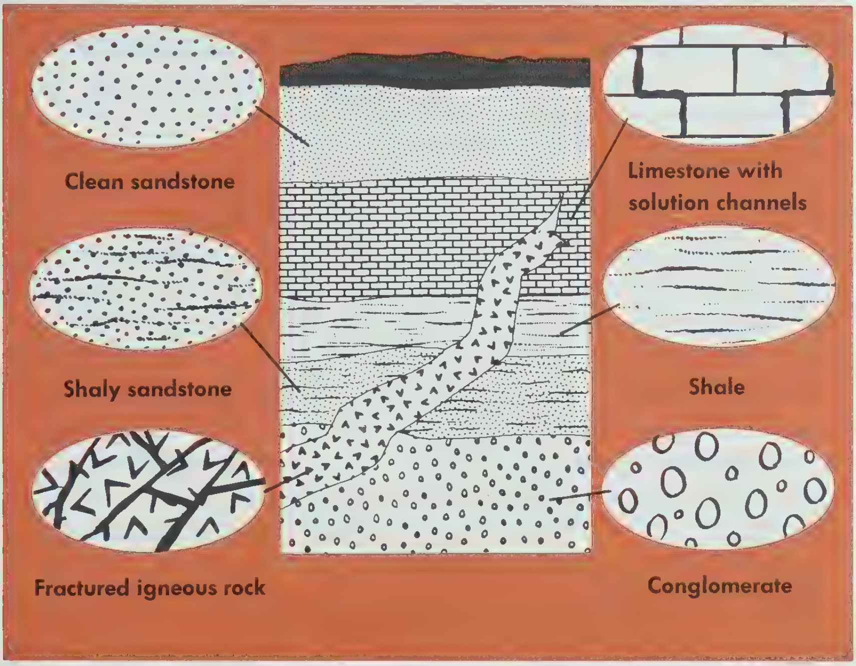


Figure 14-1. Permeability in rocks may originate during deposition as in sandstone, or after consolidation as in fractured rock or limestone solution channels.

EXPERIMENT. Fill two open-ended glass tubes with dry sand. Use a clamp and stand to hold them upright in a shallow pan or plate. Carefully pour water into one tube until the sand is saturated and some water runs down onto the plate. What happens in the tube of dry sand when the water in the plate reaches it?

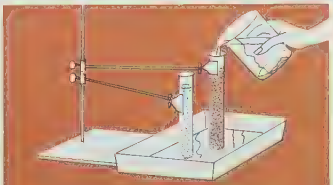


Figure 14-2.

EXPERIMENT. Place a stalk of celery or a white carnation in a glass jar. Partly fill the jar with water and add a few drops of red food coloring. Let this experiment continue for several days. What happens to the celery or flower?

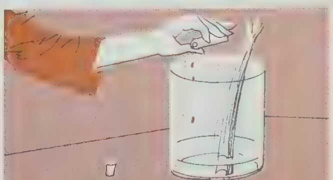
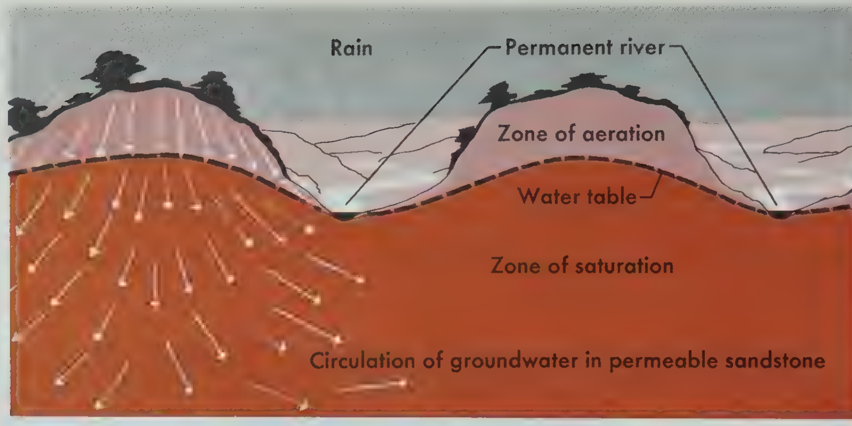


Figure 14-3.

Problem

Some agricultural scientists doubt the benefits of plowing and hoeing during a dry summer. What is their reasoning?

Figure 14-4. This cross section shows the path water takes as it infiltrates permeable rock, then returns to the surface and joins permanent streams.



Water fills all spaces in the zone of saturation.

The **zone of saturation,** or the *groundwater zone,* lies immediately below the zone of aeration. The upper surface of the zone of saturation is known as the **water table.** (Figure 14–4.) The bottom of the zone is the upper surface of a rock layer which has no openings. At depths of approximately 12 mi, the weight of overlying rocks probably seals all pores and cracks, and prevents water from sinking any deeper.

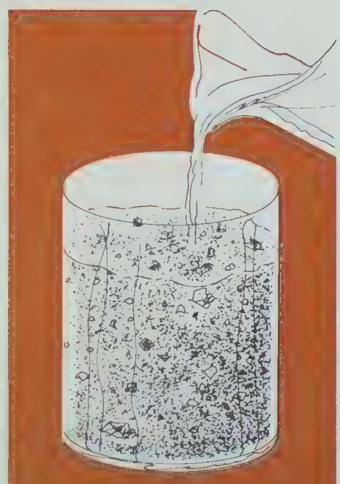


Figure 14-5.

EXPERIMENT. Fill a glass jar with a mixture of sand and small stones. Leave some room in the jar for water. Slowly pour water into the jar, but do not saturate the sand. Allow the jar to stand until all of the water has percolated to the bottom. When the upper sand becomes dry, measure the height of the damp sand. Draw a sketch of the jar and its contents to show the position of the water table. Label the part of the contents which illustrates the zone of saturation.

Now add more water to the jar. What effect does it have on the water table? If, instead of a glass jar, you used a cardboard carton with a small hole in the bottom, what would happen to the water table? Why, in most places, does the water table fall during the summer?

Relief refers to the variation in height of different land forms.

The water table is approximately parallel to the ground surface although its relief is somewhat more gentle. On hilltops, the water table is farther below the surface of the ground than it is in adjacent valleys. Water wells drilled to the water table must penetrate more rock on the hilltop than in the valley.

The water table follows the surface relief at some depth below the surface.

Depth of the water table is not constant; it fluctuates with the amount of rainfall. After each rainfall that supplies water to the underground zone of saturation, the water table rises temporarily. Light showers seldom supply enough water to percolate downward beyond the zone of soil moisture, where it may be evaporated or used by plants. But during the spring,

rainfall is at a maximum and melting snow adds to the amount of available water. In this period, the water table tends to be higher than during the rest of the year. During especially wet seasons, the water table may be close to, or even at, the surface of the ground. In periods of drought, the water table is far below the surface. Permanent rivers that have water flowing through their channels throughout the year, as well as lakes and swamps, are areas where the water table is above the surface of the ground.

14:2 *Movement of Groundwater*

Gravity causes groundwater to move from higher elevations to lower elevations, always following the path of least resistance. Groundwater flows in the same general direction as surface water, but much more slowly. Groundwater moves slowly because its speed is decreased by friction between the water and the rocks through which it flows. Eventually, water may emerge at the surface in springs, seeps, or man-made wells. (Figure 14–6.)

Water can flow through rock layers only if the rocks are *permeable* (pur′mee a bul); that is, the rocks must have connected openings so that water can move through them. Rocks may be *porous*, with many openings, but unless the openings are connected, water cannot flow. Rocks which have no openings between grains are said to be *impermeable.* Movement of groundwater depends on the slope of the rock layers, the supply of water, and the permeability of the rock layers. Rocks that have large pores which are connected so that water can flow

Aquifers are rocks which store water in connected pores.

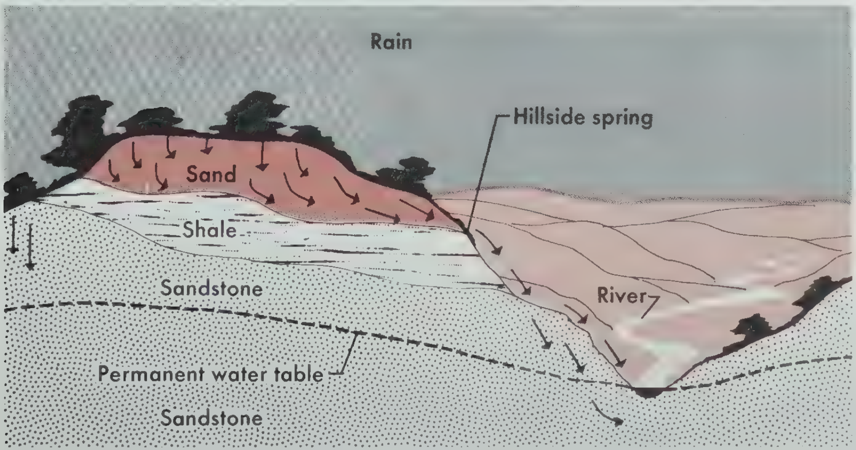


Figure 14-6. Because some rocks are impermeable, the circulation of underground water may be quite complex in regions of alternating permeable and impermeable rock.

freely are called *aquifers* (ak′wa fers). Most aquifers are made of sandstone, gravel, limestone, or sand. Wells must be sunk deep into an aquifer to insure a dependable supply of water.

Artesian water, held under pressure between layers of impermeable rock, may be forced upward through any openings to the surface.

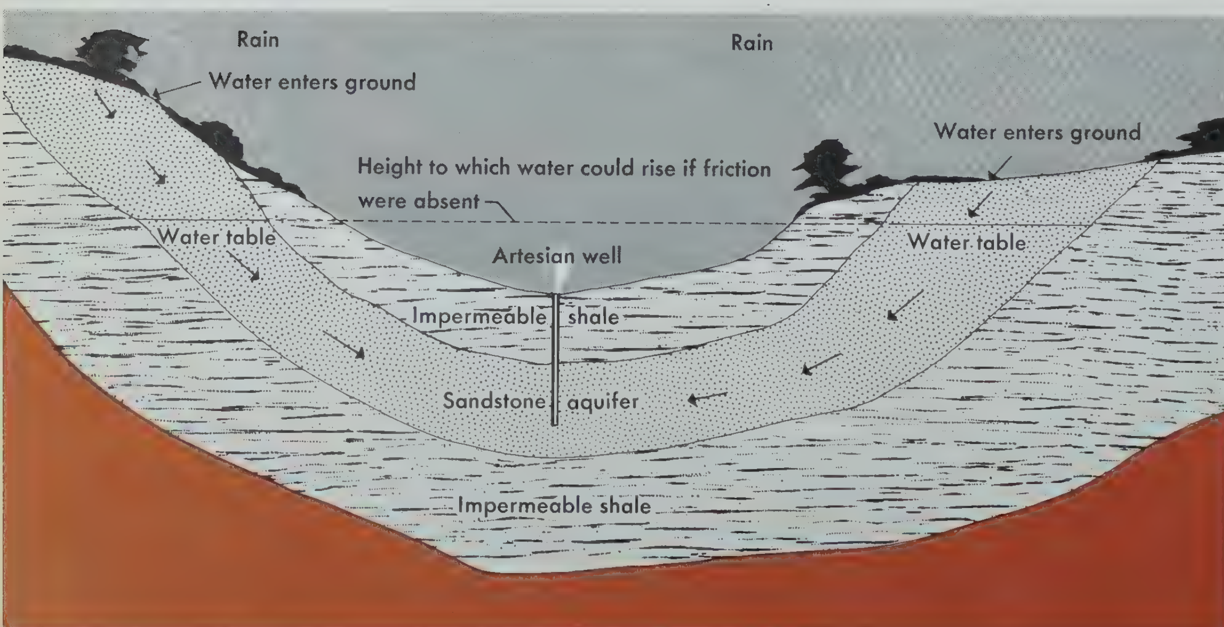
Artesian (ahr tee′zhan) **water** is a natural upwelling of water under hydrostatic pressure. Sometimes a layer of permeable rock lies between dense, impermeable rock layers. Then water moves through the permeable rock in the same way that it moves through a pipe. If the upper part of the aquifer is exposed at the surface so that its water supply is continually renewed, water will rise toward the surface by any available opening. Some openings are cracks or fractures in the rock layers. Other openings are man-made wells. In either case, water escapes upward under pressure, due to the weight of the column of water in the aquifer. Water does not rise quite as high in these openings as the elevation at which it entered the permeable layer, because it loses some energy due to friction as it flows through the aquifer. (Figure 14–7.)

Hydrostatic pressure is pressure exerted by water.

Seeps and springs are present where the water table meets the surface.

Not all groundwater is under pressure, and not all wells have artesian flow. Many aquifers yield water only when wells are pumped. **Springs** occur where water reaches the surface under pressure, and flows from a natural rock opening. **Seeps** are places where water oozes out enough to moisten the ground,

Figure 14-7. Water under pressure rises through either natural or man-made openings to form artesian springs or wells. Artesian wells were first discovered in Artois province in France about 1100.



but there is no distinct water flow. Both springs and seeps are points at which the water table meets the surface of the ground.

EXPERIMENT. *Use three 8-oz paper cups or three ½-pt milk containers with their tops cut off. Fill one container half full of sand, another half full of a mixture of sand, clay, and gravel, and the third container half full of clay. Punch a few holes in the bottom of each container and a few on the sides above the bottom. Be sure that the holes are all the same diameter and in the same places in each container. Stand the three containers on stilts made from swab sticks or on supports made of small blocks. Place all of the containers over a pan or in the sink. Pour about ¾ cup of water in each container. Does any water run out of the containers? If so, describe the appearance of the water (clear, cloudy, and so on).*

Allow the containers to stand for at least one hour. Examine them again. Are any of them still dripping? Is water standing on the top of any of the sediments? Has all of the water drained from any of the containers? Is the water that passed through the clay clear? What do you conclude about the relative permeability of the sand, the clay, and the sand-clay-gravel mixture?

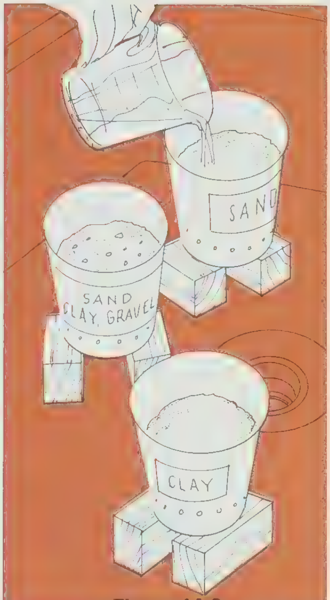


Figure 14-8.

14:3 Composition of Groundwater

Rainwater is a weak acid which contains carbon dioxide in solution. Limestone rocks, which consist of calcium carbonate, go into solution as long as rainwater flows over them and carries away the dissolved substance. Groundwater that contains more than 8 grains of mineral matter per gallon is called **"hard water." "Soft water"** contains little mineral matter in solution. The dissolved substances in soft water tend to remain in solution. Rainwater is "soft" when it falls on the land. But if it flows through a limestone region, it becomes "hard" as soon as it has dissolved sufficient quantities of calcium, magnesium, and iron carbonates. Of these minerals, calcium carbonate is the most abundant in hard water.

Rainwater is water, naturally distilled by heat of sun, which becomes a weak acid as it passes through the atmosphere and carbon dioxide is dissolved in it.

Grain is a unit of weight equal to 0.0648 g.

Deposits on the inside of water heaters and teakettles are composed of calcium carbonate which precipitates from solution when hard water is heated. A disadvantage of hard water is that it makes soap ineffective as a cleaning agent. The carbonates tend to precipitate from the soap solution, leaving a scum of dirt and oil along with the carbonates.

Rainwater is a weak acid and may dissolve calcium carbonate, sodium carbonate, or salt and carry these compounds away in solution.

In the semiarid southwestern United States evaporating water often leaves crusts of calcium carbonate on or near the surface of the ground. Such deposits are known as *caliche* (ka-lee′chee). Sodium carbonate is another component of the soil in arid regions. Calcium carbonate and sodium carbonate are usually absent in the soils of humid regions, because they are dissolved and then carried away in the runoff. Sodium carbonate gives the waters of arid regions a bitter taste. After a rain, or even after irrigation, thin white layers of sodium carbonate cover the surface where water remained for a while before it evaporated. Sodium chloride, or common salt, is another substance often found on the surface of the ground in arid regions. Salt that is dissolved in groundwater may come from layers of salt which were deposited in evaporite basins such as the Salton Sea of California. Other possible sources are saltwater trapped in sediments during their formation on the sea floor, or saltwater that infiltrated areas near the sea.

Because of their porosity and permeability, volcanic rocks are often the sites of mineral springs and geysers (gie′zers),

Figure 14-9. When water turns to steam, pressure lifts the whole column and forces it out at the surface opening to form a geyser.

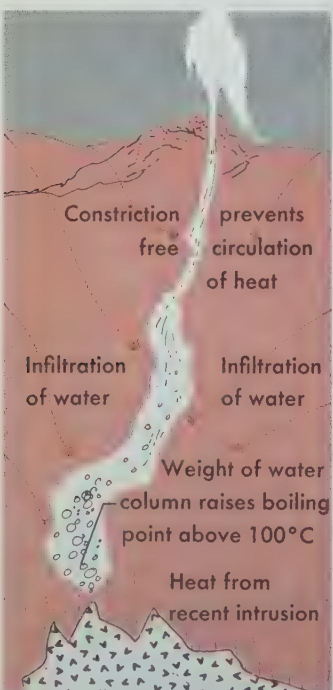


Figure 14-10. Eruption of White Dome Geyser has built up a cone of siliceous sinter around the surface opening.

National Park Service

Many of the springs in volcanic formations are heated by contact with hot magmatic bodies far below the surface. Because of their high temperatures, these waters are able to dissolve large amounts of matter. Hot springs which contain calcium carbonate, calcium sulfate, or sulfur often have a conspicuous color, taste, or odor, and are called *mineral springs*. *Geysers*, named for the hot gushing springs of Iceland, are types of hot springs which erupt through small surface openings at irregular intervals. As water accumulates in the tube or underground chamber of the geyser, it is heated and eventually turns to steam at the bottom. When the steam pressure reaches a certain value, the water in the upper end of the tube flows out onto the surface and lowers the pressure on the column of water. As the pressure on the water in the geyser tube is released, the chamber of water begins to boil. Finally, a jet of steam is thrown into the air, sometimes as high as 200 ft. The geyser continues to spew forth steam until its pressure is reduced. This process is repeated at intervals as steam pressure rebuilds and escapes.

Geysers are hot springs in which water is forced upward by steam pressure. Narrow openings at the surface cause water and steam to erupt at given intervals.

14:4 *Underground Water Deposits*

Hot springs, including geysers, contain large quantities of dissolved minerals which may be precipitated as the water cools. Precipitates around hot springs commonly contain abundant calcium carbonate. These sediments are called *travertine* (trav′er teen), if compact; *tufa* (teu′fa), if porous; or *onyx* (ahn′iks), if composed of translucent layers. If the spring water has traveled through igneous rock, deposits may consist of a milky colored silicate called *siliceous* (sa lish′as) *sinter*.

Groundwater transports, deposits, and concentrates valuable minerals such as copper, lead, zinc, silver, and gold. Such concentrations occur along rock fractures and faults, or between rock layers. Groundwater also helps to consolidate sediments into hard rock layers. Sediments may be cemented by the precipitation of minerals between grains of sand, gravel, or lime. Some of these sedimentary rocks become valuable building stone.

Groundwater may help to concentrate certain ores and some minerals.

Replacement is another process by which groundwater changes rocks and minerals. Some elements of the rock go into solution and are replaced by elements from the groundwater.

Figure 14-11. Terraces of travertine have been deposited by these hot springs.

National Park Service

Wood cells replaced by silica become petrified wood.

Petrified wood results from the replacement of wood fibers by silica (SiO_2). As the wood fibers decay, silica takes the place of the original woody materials. Gradual replacement preserves the exact shape of the bark, tree rings, and cellular structure. Although complete petrification usually requires many years, under favorable circumstances it may occur within a few months or even weeks. Petrified wood of gem hardness is found in flood plain sediments once submerged beneath waters that carried large amounts of volcanic ash.

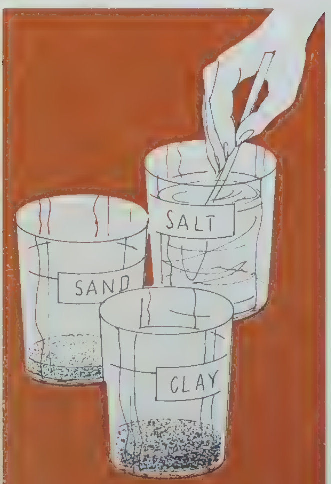


Figure 14-12.

EXPERIMENT. Pour ¼ cup of salt into a clear glass or plastic container, ¼ cup of clay into a second container, and ¼ cup of sand into a third container. Add water to each container and stir well. What happens in each container?

From your observations, explain the distribution of sandy materials and clay in the soil. What happens to the salt, clay, and sand that is carried away by streams? If water does not run off the surface, but trickles through the soil to some depth, what happens to the clay and to the sand?

Problem

Recall the principles you learned about the solution of sedimentary rocks in Chapter 6. Which sedimentary rocks might go into solution? (To answer this question, you may wish to repeat the experiment in Section 6:8 using dilute hydrochloric acid on several sedimentary rocks.)

14:5 *Topography of Limestone Areas*

Limestone regions offer the best evidence of the chemical action of groundwater. Limestone consists mainly of calcium carbonate, which is soluble in a weak acid such as rainwater. Much of the soluble limestone may be carried away by groundwater, leaving features known as sink holes, caves, caverns, solution valleys, and natural bridges. The resulting landscape is called *karst topography*, after the honeycombed limestone Karst area on the eastern side of the Adriatic Sea.

Sink holes may appear in a level, dry landscape where water descends from the surface along joints, cracks, and other openings in the rock. *Sink holes* are depressions shaped like large funnels with their outlets downward. Surface waters drain into these sinks and, if mud collects and blocks the outlet, form deep lakes. The Bottomless Lakes in New Mexico are actually water-filled sink holes.

Sink holes are circular, funnel-shaped depressions formed in rock joints where water has descended to join the underground water.

Water may seep downward slowly, dissolving soluble materials and forming *caves* and *caverns* in rock which is particularly soluble. Caverns, such as those at Carlsbad, New Mexico, consist of a number of caves which are joined by narrow passageways. Often the true extent of such a system of caves is unknown. Once a cavern system has developed, a stream of water often flows through the large tunnel-like opening and eventually emerges at the surface to join the runoff. Mammoth Cave, Kentucky, has such a stream flowing through it. Florida's springs are also outflowing underground streams. Most underground water moves slowly between layers of rock or through rock pores, instead of flowing swiftly like a river. However, it still is an effective erosional agent.

Caves and caverns are common underground features in limestone areas.

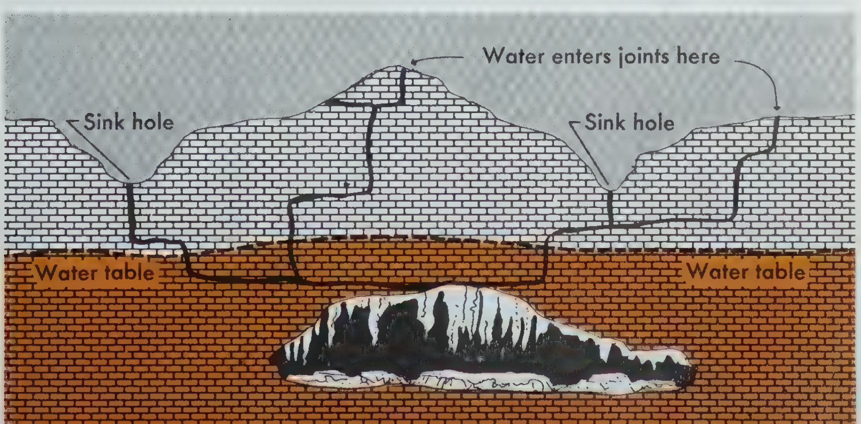


Figure 14-13. Limestone that goes into solution along joints and bedding planes above the water table is often precipitated in caves in the zone of saturation.

Figure 14-14. Weathering and erosion have left the more resistant rock suspended above a deep gorge worn in the weaker rock below.

W. T. Lee, U.S. Geological Survey

Solution valleys and natural bridges are formed when the roofs of caves and caverns collapse. A *natural bridge* is the section which remains when adjoining roof sections have collapsed. If an underground stream flowed through the cavern, it now becomes a river flowing in a *solution valley*. The river removes the collapsed-roof material of its former tunnel.

Stalactites and stalagmites are deposits of calcite formed by water dripping slowly from the ceiling of caves.

Deposits suspended from the ceilings of caves are called *stalactites* (sta lak′tiets). Deposits built up from the floor are called *stalagmites* (sta lag′miets). These formations result from slow precipitation of the mineral calcite ($CaCO_3$). As water loaded with calcite drips from the roof of a cave, some

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Figure 14-15. Water dripping from the cave ceiling has deposited the icicle-like stalactites above and the mushroom-shaped stalagmites below.

of it evaporates and leaves the hanging stalactite. As the stalactite continues to drip like a melting icicle, a stalagmite is built up from the floor below it. When the two forms meet, they become a pillar or column. Carlsbad Caverns, New Mexico, contain beautiful examples of these formations.

14:6 *Importance of Groundwater*

Transportation, deposition, and concentration of minerals are important functions of groundwater. Many industries utilize these deposits of silver, copper, lead, zinc, and other ores. However, the most vital use of groundwater is to supplement surface water for human consumption.

At present, rainfall is the major source of water available for use by man. A large portion of rainfall is lost to the atmosphere by evaporation and transpiration of plants. The remainder becomes either runoff or groundwater. Runoff supplies water to surface bodies such as rivers, lakes, and man-made reservoirs (rez′urv wahrs). Groundwater is stored in the zone of saturation. But recall that both runoff water and groundwater return to the oceans during the hydrologic cycle.

The water table is being lowered by the excessive use of water.

More than half of the runoff and groundwater of the world is outside man's living area, and it returns to the ocean unused by man. The remainder of earth's water supply is used in industry, in agriculture, and for domestic purposes before it is returned to the sea. When surface water supplies are inadequate or polluted, groundwater must be tapped. One of today's challenges is finding enough pure water for the needs of our growing population and industry. Surface water not only is being used at an increasing rate, but also is being heavily polluted by industrial, agricultural, and urban wastes. Polluted water cannot be used until it is purified. Because groundwater accumulates slowly, pumping water from the zone of saturation lowers the water table at an alarming rate in many regions.

Several possible solutions to our water problems are under study. Attempts are being made to remove salt from ocean water at reasonable costs. Studies have been undertaken of methods for purifying surface water and returning some processed water to ground storage. Scientists are trying to find more efficient ways to use irrigation water in arid regions and to prevent evaporation and seepage of water from reservoirs. One of the more promising solutions is the diversion to cities of the presently unused rainfall which flows back to the ocean.

The supply of pure water must be increased and must be used more efficiently.

MAIN IDEAS

1. Water which sinks into the ground is part of the hydrologic cycle.
2. Some underground water is held near the surface by capillary attraction; some underground water percolates through the zone of aeration and collects as groundwater in the zone of saturation.
3. The water table is the upper surface of the zone of saturation, and lies almost parallel to the surface relief.
4. Groundwater joins surface water through springs, seeps, and wells. Seeps and springs appear where the water table intersects the surface of the ground. Artesian water, confined between layers of impermeable rock, is under great pressure. Artesian flow occurs when a well, or some other opening, extends from the surface to the aquifer in which the water is confined.
5. Aquifers are rocks with connected pore spaces in which water can be stored effectively.
6. Because rainwater is a weak acid, it will dissolve calcium carbonate, sodium carbonate, salt, and certain other minerals. These substances may be redeposited in a different environment due to evaporation or a chemical reaction of the water in which they are contained.
7. Hot springs often contain calcium carbonate, calcium sulfate, sulfur, and silica in solution. Water of these springs may be heated by contact with hot magma in regions of volcanic activity.
8. Geysers are hot springs which erupt at intervals. Because openings to the surface are narrow, water cannot flow continuously as it does in other hot springs. Eruptions occur when steam pressure builds up sufficiently to force the water through the narrow opening.
9. Topographic features in limestone areas include sink holes, natural bridges, underground river tunnels, solution valleys, and caves. These features are formed during solution of limestone by groundwater.
10. Stored groundwater should be conserved and used more efficiently because it is of vital importance to life on earth. Studies are being made of new and better ways to control water for future use.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

aeration	capillary	saturation
aquifer	geyser	stalactite
artesian	permeable	stalagmite

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Groundwater is one part of the hydrologic cycle.
2. Air is present in the zone of oxidation.
3. Water table is the upper surface of the zone of aeration.
4. The water table is almost parallel to the surface relief.
5. Artesian water is stored in an impermeable rock layer.
6. Most groundwater moves toward sea level.
7. Gravity is the force which causes groundwater to flow.
8. Sediments are cemented by substances precipitated from groundwater.
9. Sand commonly is carried downward farther than clay by percolating groundwater.
10. Most of the rain and snow which fall on land become groundwater.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. A small hair-like tube is called a(n) (*aquifer, reservoir, capillary*).
2. Groundwater is stored in the zone of (*oxidation, saturation, aeration*).
3. Rock which has connected openings through which water can percolate is (*impermeable, permeable, impervious*).
4. In a (*seep, geyser, stalactite*), water is forced to the surface by steam pressure.

5. The water table is closest to the surface of the ground (*on a hilltop, on a hillside, in a valley*).
6. The most impermeable type of rock is (*shale, sandstone, limestone*).
7. Hot springs are commonly associated with regions of (*volcanic rock, shore deposits, karst topography*).
8. Two of the following which are most likely to be concentrated by groundwater action are (*coal, copper, lead, diamonds, emeralds*).
9. In arid regions, a hard crust of calcium carbonate is often left on the ground when groundwater is evaporated. This substance is called (*travertine, onyx, caliche*).
10. Karst topography is in areas of (*limestone, granite, lava*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Water which collects below the water table is called __?__.
2. Rock capable of storing water is called a(n) __?__.
3. Some underground water is held near the surface by __?__ attraction.
4. A lake made by man for water storage is called a(n) __?__.
5. Hot springs that erupt at intervals are called __?__.
6. Many hot springs contain __?__, __?__, and __?__.
7. Calcium carbonate deposits found near hot springs include __?__, __?__, and __?__.
8. Petrified wood is formed when wood fibers are replaced by __?__.
9. Three features commonly found in karst topography are __?__, __?__, and __?__.
10. As groundwater that contains calcite drips from the roofs of caves and caverns it forms __?__ and __?__.

D. How and Why

1. Why does water erupt from a geyser? Use a diagram to illustrate your answer.
2. Why do some citrus growers in semiarid climates plow between trees, or plant grass cover?

3. Why is the zone of aeration called the zone of oxidation?
4. Why do authorities in some arid and semiarid localities prohibit the sinking of wells on private property?
5. Why should sand overlie clay layers in a flower bed?
6. Why are layers of caliche and salt found on the surface in arid and semiarid climates but not in humid climates?
7. Why do wells along the seashore sometimes become salty?
8. What kind of rock underlies the Florida Peninsula? (Clues to the kind of rock are found in the presence of disappearing rivers, springs, and funnel-shaped lake beds.)
9. What conditions along the Florida seacoast indicate the possible presence of great thicknesses of limestone? Explain your answer.
10. What is hard water, and where is it found?

INVESTIGATIONS

1. Investigate the depth of the water table in your locality. Contact your local water department or your state department of natural resources for maps and data. Discuss the problems of supplying pure water for your community. In addition to human consumption, how is water used in your community?
2. Report on water witching or dowsing. Is it based on scientific facts or is it superstition?
3. What is spelunking? Is it of any scientific value? What are some of the dangers and how should they be avoided? Report on the work of some discoverers of famous caves.
4. If you have seen the springs and geysers of Yellowstone Park or some other place, report on your observations.

INTERESTING READING

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Glaciers

Like surface water and underground water, masses of ice move under the influence of gravity. Although the ice masses move more slowly than water, they are more abrasive because of their great weight and rigidity.

Rivers are far more important than glaciers in erosional work, but in some regions glaciers have played a significant part in changing the surface of the earth. In fact, much of northern North America has been shaped by glaciers.

15:1 *Origin*

Glaciers are composed of four layers: new snow, ice granules, firn, and interlocking crystals of ice.

Glaciers are masses of ice in motion. They are formed by the accumulation of snow and ice. On the surface of a glacier, snow remains in flakes, just as it fell. Below the soft, new snow, some melting occurs. Here, the flakes combine to form rounded *granules* (gran′euls). Below this zone, pressure from the overlying layer compacts the granules into a permeable mass called *firn*, or névé (nae vae′). If snow accumulates for at least two seasons and reaches a depth of 100 ft to 200 ft, the buried snow layer becomes an impermeable block of interlocking ice crystals. This is *glacier ice*. The process which changes snow to firn ice resembles the compaction of sediments to form sedimentary rock. Recrystallization of firn ice to larger crystals of glacial ice resembles the recrystallization of sedimentary rock to form metamorphic rock under pressure.

A **snowfield** is an area of permanent snow. A **snow line** is the lower boundary of a snowfield.

In a snowfield, snow remains on the ground from year to year. Snowfields extend down mountain slopes to an altitude where melting counterbalances additions of new snow. This altitude is called the *snow line*. Below the snow line, melting prevents accumulation of snow during the warm season. Above the snow line, snow continuously occupies the area. The extent of a snowfield depends upon topography, temperature, and the

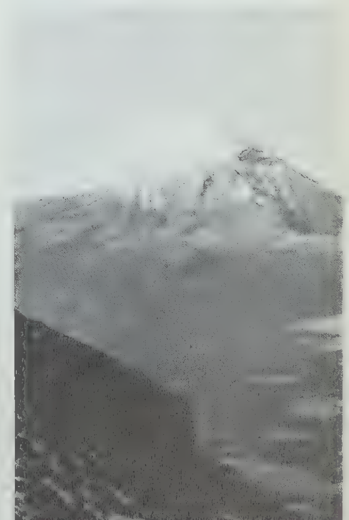
H. W. Walton

Figure 15-1. When a sufficient thickness of ice accumulates, valley glaciers move downslope usually following a previous river channel.

amount of precipitation. Steep open slopes are bared by snowslides, wind scour, and exposure to the sun. Hollows that shade the snow prevent melting and promote glacier formation. In humid regions, where temperatures are below freezing, snowfields may be large and extend to low altitudes. In warmer or drier regions, snowfields may be limited to high altitudes.

As snow accumulates on the surface of a snowfield, pressure from the overlying layer changes buried snow into ice. Bottom ice becomes plastic or pliable and begins to flow. Surface ice remains brittle because it is not subjected to loading. During movement, tensional stresses cause the surface ice to break and form cracks or *crevasses* (kri vas′ses) 100 ft to 200 ft deep. Tension develops as the plastic bottom ice flows over irregularities in the channel or as the surface ice clings to the rock wall while the center section of the glacier moves downslope more rapidly than the outer section. Meltwater drips into these cracks and forms streams within or below the ice. Deposits of sand and gravel, called *eskers*, left by receding glaciers indicate where such streams once flowed.

Figure 15-2. High mountains often have snow all year because temperatures are too low for melting to occur.



Julia Moseley

Figure 15-3. Below the snowline, glacial meltwaters carry away great quantities of debris.

Edward J. Webster

Some surface snow is lost by evaporation. At its lowest limit, a glacier loses some ice by melting. If the ice melts faster than the snow accumulates, the glacier recedes. If melting is balanced by the forward movement of ice, the glacier front remains stationary. If snowfall in the snowfield exceeds the rate of melting throughout the glacier, the glacier increases in size and spreads to lower elevations or lower latitudes.

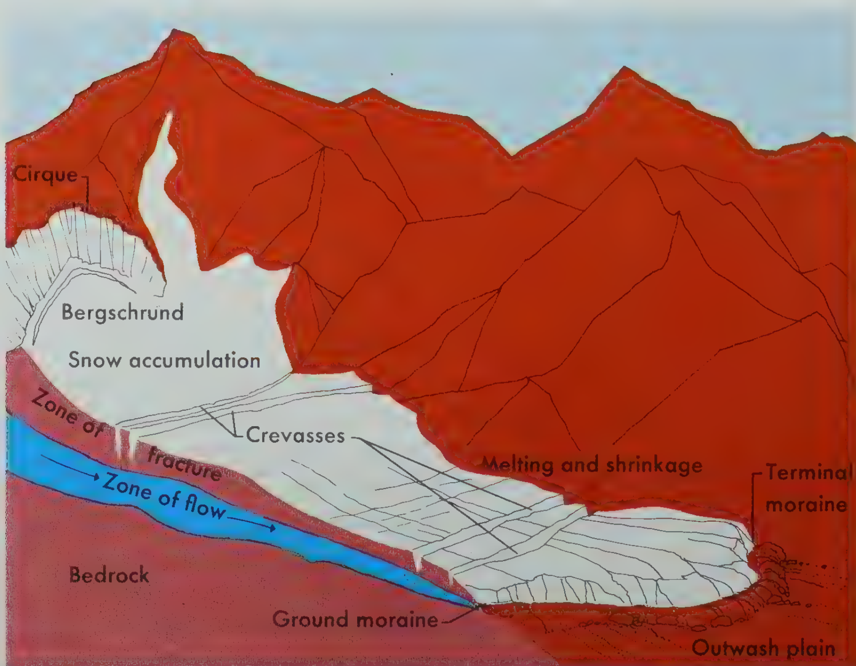


Figure 15-4. As a glacier moves downslope over an uneven channel, the surface ice is broken into deep crevasses; the bottom ice flows over the irregularities.

EXPERIMENT. Place two large ice cubes in a shallow pan. Put a large piece of iron or a brick on one of them. Which cube melts faster?

Put two more ice cubes in the pan. Cover one ice cube with a square of heavy white paper. Cover the other ice cube with a square of heavy black paper. Which cube melts faster?

Now place two large ice cubes in a shallow pan. Place a key or heavy nail on one ice cube and put the pan in the freezing compartment of a refrigerator. Leave the pan in the refrigerator for several hours or overnight. Examine the ice cubes. Where is the key or nail? Explain what has happened. If you live in a region where freezing occurs, list some examples which illustrate this principle.

Summarize your conclusions regarding the influence of heat absorption and pressure on melting.

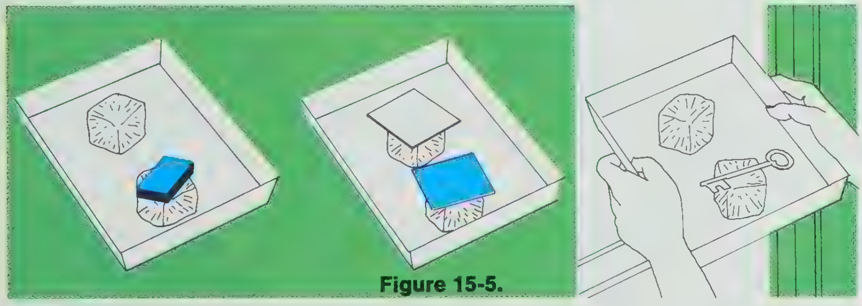


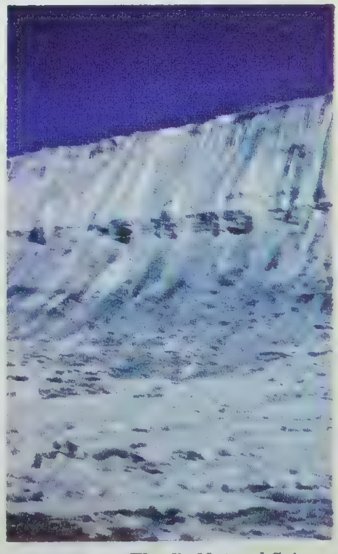
Figure 15-5.

15:2 *Location*

Glaciers form in high latitudes or at high altitudes—places where heavy snowfall collects and remains throughout the year. Glaciers that originate on mountains are called *mountain*, or alpine, *glaciers*. Mountain glaciers become *valley glaciers* when they move down major mountain valleys in response to the pull of gravity. Mountain glaciers are more extensive in high latitudes than in low latitudes. In Alaska, valley glaciers extend downward to the base, or foot, of the mountains, where they join to form a continuous mass of ice. These glaciers are known as *piedmont* (peed′mahnt) *glaciers* because they form a plain of ice at the foot of the mountains.

Glaciers that form in high latitudes where heavy snowfall but little melting occurs are called *continental glaciers*. Today continental glaciers exist only in Antarctica and Greenland. Because these glaciers are small compared to the continental glaciers of the past, they usually are called *ice caps*. However,

Figure 15-6. Wilson Piedmont glacier, marked by numerous meltwater gullies, ends abruptly at the mountain foot where melting counterbalances ice movement.



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because Antarctica and Greenland are covered continuously with ice that moves out in all directions due to its weight, both of these areas have true continental glaciers.

Evidence from both erosion and deposition indicates the former presence of a continental glacier over much of Canada and northern United States.

Continental glaciers cover valleys, plains, and even mountains with ice that is thousands of feet thick. Greenland's ice cap is a small remnant of an ice blanket that once covered northern Europe, northern Asia, and North America as far south as the Ohio River Valley. During the advance of this great continental glacier, snow probably accumulated near the present Hudson Bay. As ice formed thousands of feet thick, its weight caused the bottom ice to move outward in all directions. Movement was most rapid around the outside edge where the ice was thinnest. As this great mass of ice moved across the rock beneath, it removed all loose fragments and scoured basins in soft rock. Resistant rock was polished and sometimes scratched by debris carried in the bottom of the ice. Because mountain glaciers occupy channels and move downward, they could not have eroded the New England mountain tops. But the tops of New England's hills were planed, gouged, and polished by ice action. The height of these hills is a good measure of the thick-

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Figure 15-7. Snow fills the hollows and ice fills the valleys in this mountainous region.

ness of North America's continental glaciers. Continental glaciers 8,000 ft to 10,000 ft thick must have been present to cover these hilltops with enough weight to cause erosion on the hilltops.

15:3 Erosion

Because running water has affected large areas since the earth was first formed, it has been more effective than glaciers in reducing continents to sea level. But glaciers erode more deeply than rivers, because glaciers carry a much more massive load of boulders, gravel, and sand.

Glaciers acquire their load of sediments at the bottom of continental glaciers and at the bottom, sides, and top of valley glaciers. Sediments frozen into the ice of valley glaciers are carried forward as the ice moves downslope. In continental glaciers, the sediments are carried outward from the center.

The erosive power of a glacier depends on its thickness. Ice that is thousands of feet thick can transport boulders tens of feet in diameter. Many of these boulders are plucked from the bedrock and carried along by the ice as it moves forward. *Plucking* occurs when meltwater from the surface or within the ice mass flows downward until it penetrates joints in the rock over which the ice is moving. When the meltwater freezes, it becomes a part of the moving glacier, and so does the rock which is surrounded by it. Glaciers accumulate massive loads of boulders, gravel, and sand, which soon change white, gleaming ice into a dark, muddy, flowing mass.

With abrasives gathered by the ice, a valley glacier scrapes the sides and bottom of its channel as a giant rasp might gouge a hollow in a log. Because continental glaciers are not confined to channels, they scrape rock surfaces over a wide area beneath the ice.

In mountains, snow collects in *cirques* (surks), hollows which are shielded from winds and shaded from the sun. Meltwater trickles down the opening between the snow and the rock wall of the mountain. In these cracks, meltwater freezes and expands with force. Its wedging action breaks the mountain face into rock fragments, which are added to the ice. Between the ice and the rock wall a crack, called the *bergschrund* (burg' schrund), is repeatedly filled with new snow. As ice wedging recurs, the original cirque becomes larger, and the rock wall of the mountain is eroded.

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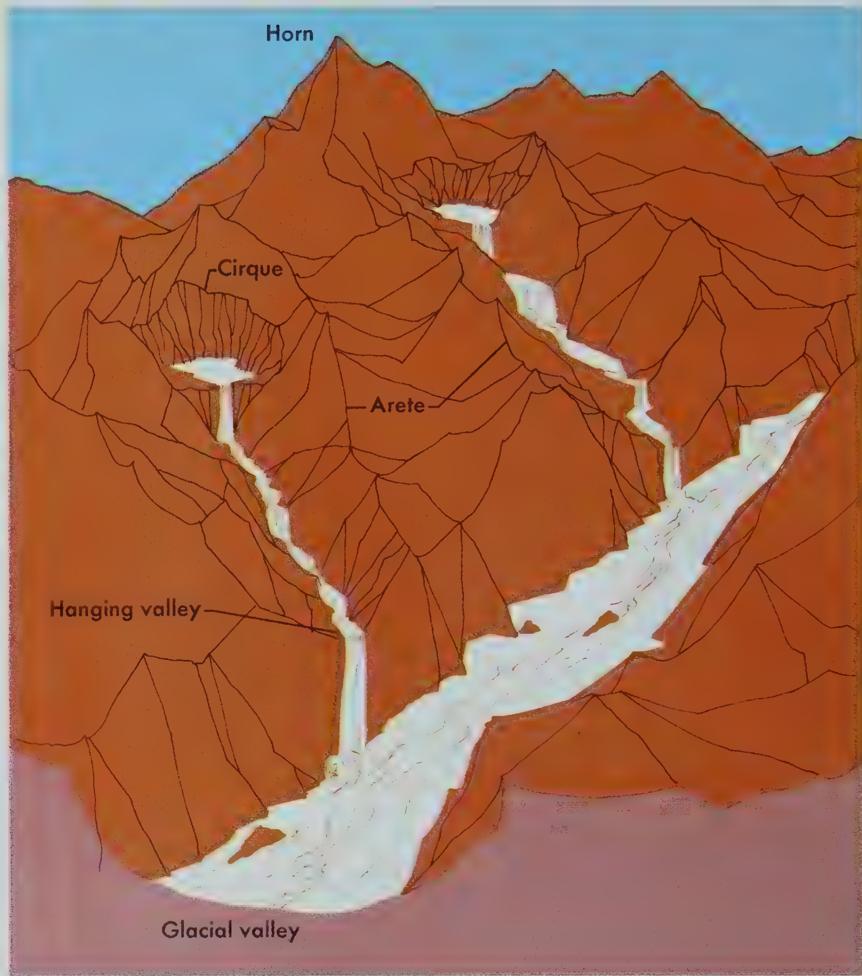
Figure 15-8. Large boulders plucked from bedrock beneath the glacier form a large part of the ice-transported debris along the Greenland Coast.

Figure 15-9. This cirque, a natural amphitheater, was formed by alternate thawing and freezing of ice during Pleistocene glaciation.

Phyllis G. Lewis

Figure 15-10. **Features formed above and beneath the ice remain as clues to glacial erosion long after the ice disappears.**



Many mountain summits have rock remnants with steep-sided, three-cornered peaks above the highest cirques. Such rock remnants are called *horns*. The Matterhorn in the Alps is a familiar example. Thin rock walls with upward pointing jagged edges separate one glacier from another. These *aretes* (a raets′) add debris to the valley glacier surface.

Glacial valleys are U-shaped.

Glaciers that begin on mountain summits occupy channels that originally were mountain stream beds. As the glacier moves downslope, the V-shaped stream channels are abraded into steep-sided U-shaped valleys. From place to place, tributary channels from side ravines join the main glacier. Because the main glacier is much thicker than its tributaries, the main channel is eroded more deeply. Thus, tributaries join the main glacier at much higher elevations than the main channel. Small glaciers from side valleys enter at right angles, because ice cannot turn corners easily. Special features of valley glaciers

are not apparent until the ice melts. Then the channels of side glaciers are left as *hanging valleys* above the main channel. Yosemite (yoh sem′it ee) Park, California, is famous for its hanging valleys and beautiful waterfalls.

Because ice is rigid, a glacier slides up and over resistant material in its path. It gouges out soft areas and leaves step-like irregularities of resistant rock in its bed. High areas are planed, smoothed, and polished. Rock surfaces, and even individual boulders carried by the ice, are marked by grooves and *striations* (strie′ae shuns), or scratches, showing that the ice contained debris with sharp edges.

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Figure 15-11. Striations are useful guides to the direction of glacial movement.

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Figure 15-12. Yosemite National Park is famous for its hanging valleys, its waterfalls, and its ice-carved U-shaped valleys.

Canada's Shield area consists of polished and striated bedrock which has been uncovered by continental glaciation.

The Canadian Shield area, which was covered by the continental glacier in Canada, exhibits many evidences of glacial erosion. The continental glacier scraped loose debris from the hard rock floor and carried it southward to the northern United States. Rocks of the Canadian Shield are polished, grooved, and striated. Many small depressions, now filled with water, were gouged from soft materials. Because ice covered this region until 11,000 years ago, weathering and erosion have not had time to destroy the marks of the glacier.

EXPERIMENT. Arrange a board at an angle that will support a flat, heavy rock and not let it roll down the slope. Different angles and different sizes of rock should be used in the experiment and results compared. Form a thick slab of "silly putty," and place it at the top of the sloping board, a short distance above the position of the rock. After 24 hours, observe what has happened to the putty. What has happened to the rock? After several days, observe what has happened to the putty and to the rock. Remove the rock from the board and place some pieces of gravel or broken shell in the path of the putty. If flat, angular pieces are used, they will tend to remain on the board without rolling. After 24 hours, observe what has happened to the gravel or shells.

Why is putty instead of ice used in this experiment? What force moves the putty down the slope? Will the same force move ice?

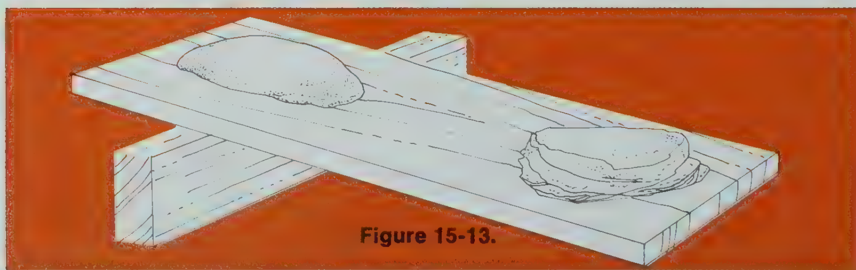

Figure 15-13.

15:4 *Glacial Deposits*

At some time in the life of a glacier, melting occurs. Then the ice can no longer retain its debris. If its valleys empty into the sea, fronts, or *snouts*, of the glacier break off and float away as icebergs. Snouts of other valley glaciers melt as they reach lower altitudes and warmer temperatures. The outermost edges of ice sheets recede as climates become warmer. Eventually the entire glacier shrinks.

Ewing Galloway

Figure 15-14. Portage Glacier, Alaska, where the snouts or lower extremity of the glacier extends into open water, breaks off, then floats away.

As ice at the front of a glacier becomes water, the glacier drops much of its sediment load directly. This unsorted material, called *drift* or *till*, forms a ridge known as a *terminal moraine* (term′nal · ma raen′). A terminal moraine within a valley dams its channel and creates a lake. Terminal moraines formed by continental glaciers indicate the farthest advance of the glacial ice.

Moraines become higher and higher as long as the forward movement of the ice equals its rate of melting. If melting exceeds forward movement, the ice front recedes and debris is scattered over a wide area in a *ground moraine*. Ground moraines are relatively smooth horizontal surfaces. The deposits are a mixture of boulders, gravel, sand, and clay. Beneath the ground moraine, old river valleys have been filled and hills have been planed. Occasionally, small clusters of hills, called *drumlins* (drum′lins), dot the ground moraine. Drumlins are fine glacial clay hills of drift shaped like cigars. The highest elevations associated with glacial deposits usually are terminal moraines. If the ice front has halted and retreated repeatedly, other high ridges, called *recessional moraines*, will parallel the terminal moraine.

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Figure 15-15. This Greenland valley is filled with rock fragments left behind by the melting glacier.

Figure 15-16. This moraine is formed of debris carried downslope and deposited where melting and forward movement of the valley glacier are equal.

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Figure 15-17. The topography of a glaciated region is fashioned by deposits beneath and in front of the ice.

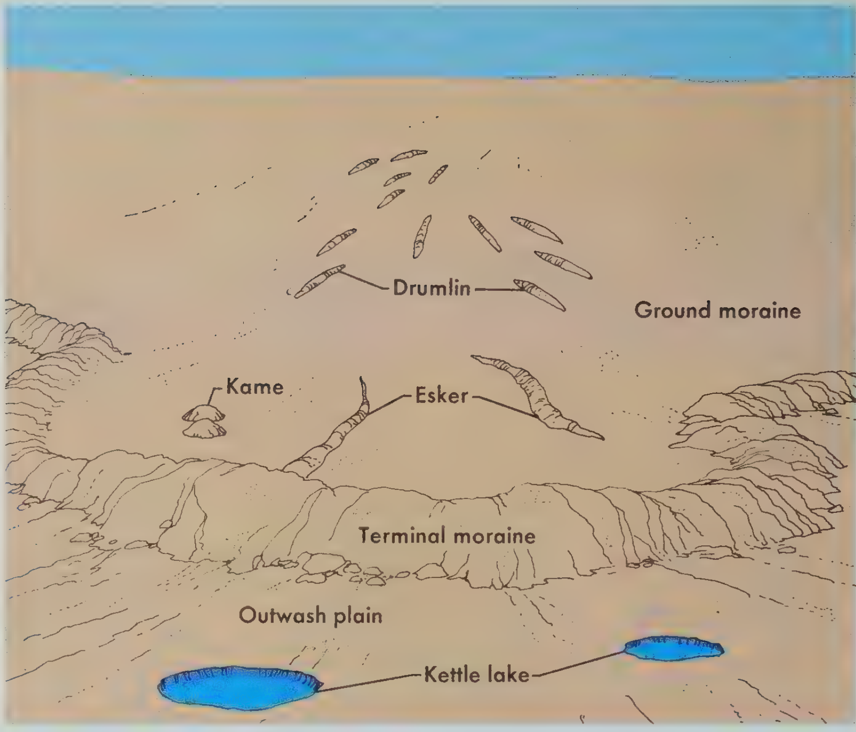

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Figure 15-18. An outwash plain, consisting of sand and gravel which was deposited by water flowing off the front of a retreating glacier, is located downslope from the moraine and consists of finer debris.

Figure 15-19. Glacial lakes formed in depressions left by the retreating glacier.

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Meltwater flows off the ice front as a sheet. It drops sand and gravel in wide gently sloping deposits which fan outward from the terminal moraine in the manner of alluvial cones. (Section 13:5.) These deposits, called the *outwash plain*, merge with terminal moraines or with recessional moraines. Occasionally, rounded gravel hills, called *kames*, are built near the terminal moraine by swirling water that pours off the ice front. Like eskers (Section 15:1), kames are composed of sand and gravel. But eskers are long ridges which formed beneath or within the ice. They lie perpendicular to the terminal moraine and settle onto the ground moraine when the ice melts.

Sometimes blocks of ice become detached from a glacier and are buried by drift. As the ice block melts, material from above sags into the depression left after melting. *Kettle lakes*, which pit the surface of both outwash plains and ground moraines, are formed in such depressions.

Moraines are associated with both continental and valley glaciers. When formed by continental glaciers, they extend for hundreds of miles but are seldom more than 100 ft high. Moraines formed in valleys are small features which seldom remain long after the valley glacier melts. However, moraines may dam water that flows through former glacial valleys. Such valleys, as the Finger Lakes of New York State, may occupy tributaries which spread out like fingers.

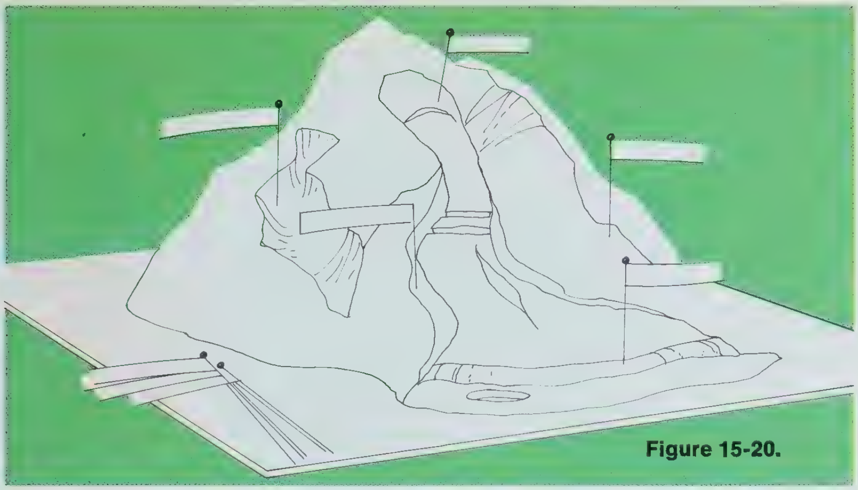

Figure 15-20.

ACTIVITY. Make a model of a valley glacier, using several colors of modeling clay. Use a square of heavy cardboard as a permanent mounting. Form the mountain of the darkest clay and fashion hollows and valleys in which to show the presence of the glacier. Indicate the various features of the glacier, as well as deposits in front of the ice. Label each feature with a paper pennant. Be sure to include a cirque, crevasses, a terminal moraine, and a lateral moraine. Slice through the model in a vertical direction to show various features and layers.

Figure 15-21. The Finger Lakes of New York State occupy old river valleys dammed up by glacial debris.

15:5 *Evidence of Glaciation*

Canada and northern United States show abundant evidence of a continental glacier. The glacier removed all loose debris from the Canadian Shield and polished and striated the solid rock beneath. It planed New England's hills to smooth, rounded surfaces. In addition, the glacier moved large, individual boulders, some 6 ft to 10 ft in diameter, from their source area, and striated and polished them. Further evidence of glaciation is found in drumlins, eskers, kames, and kettle lakes that dot the ground moraine and outwash plains.

The Great Lakes of the central Canadian border region illustrate how glacial erosion and deposition may change old river drainage patterns. Apparently, the present Great Lakes were river valleys that were deepened and widened as the ice pushed southward. When melting occurred, these depressions filled with water and became great inland bodies of fresh water. At one time, the Great Lakes were much larger than at present. Beaches and other shore features were deposited in Michigan, Indiana, Illinois, and Wisconsin on land that is now far above lake level. Early drainage from the lakes flowed through the Chicago River to the Mississippi River drainage basin. As melting gradually removed ice from the Canadian region, the Chicago River drainage route was abandoned. Finally, the present drainage route through the St. Lawrence River was developed. This new route is at a lower level than that of the Chicago River route. Some changes in the drainage of the Great Lakes occurred because the crust rose after the retreat of the ice. The great downward pressure of the ice due to its weight depressed the northern area. When the weight of the ice was removed, the crust resumed its pre-glacial position. But this elevation is higher than the elevation that determined the earlier drainage pattern.

Ancient river beds were enlarged into the Great Lakes during the last continental glacier.

World climates were affected by melting of the ice. Even climates in regions that were not involved directly in glaciation became much more humid than they are now. Such a humid climate is called *pluvial*, (ploo′vee al), a term which means rainy. During the retreat of the ice, even the now semiarid areas of western United States were humid. Lake Bonneville spread westward from the foot of the Wasatch Mountains across much of Utah and Nevada. This former lake, which covered about 20,000 mi^2 with water to a depth of 1,000 ft, dwindled until only the Great Salt Lake of Utah remains. The former size

The world had a pluvial climate during the melting of the continental glaciers.

Figure 15-22. As the Pleistocene glacier advanced southward, it followed a former drainage system and deepened and widened old river channels in which lakes now stand.

of Lake Bonneville is revealed by shore features now stranded high above the Great Salt Lake. Because weathering and erosion are exceptionally slow in a desert climate, the old lake features have been preserved.

15:6 *Theories of Glacial Origin*

At least three ice ages have occurred during the geologic past.

At least three times during the earth's history, continental glaciers have appeared, made their mark, and then departed. The earliest glacier appeared over 600,000,000 years ago. The next period of glaciation occurred about 200,000,000 years ago. However, this glaciation did not affect the northern hemisphere. Only Africa, South America, India, and Australia were glaciated. The most recent glaciation began less than 1,000,000 years ago and retreated from North America about 11,000 years ago. Ice caps at the poles are remnants of this most recent glacial event.

Ice ages may be related to a shift in position of the earth's poles.

Many theories have been suggested to explain why glaciers have occurred at such widely separated times, and in such widely separated places. One suggestion is called the *wandering poles theory*. Perhaps the earth's poles have not always been in the same position with respect to the continents. Then, when either pole was in the ocean, ice could not accumulate. But, when the poles were on land, snowfall could remain and eventually become ice. Another idea suggests that the amount of radiation received from the sun has varied from time to

Decreased radiation may have caused lower temperatures and growth of ice fields.

Increased radiation received by earth may have resulted in increased evaporation and more snowfall at the poles.

time. When the earth received less heat than normal, glaciation could occur. Temperatures fell, more snow accumulated, and ice advanced to lower and lower latitudes before it melted. According to another theory, glaciers formed during an increase in radiation from the sun. The increased heat caused increased evaporation, and increased precipitation. Eventually, a dense cloud cover shut out heat from the sun and the earth became colder. Increased precipitation resulted in increased snow accumulation at the poles.

Like the theories of the earth's origin, present theories of glacier origin are not completely acceptable. They do not answer all questions about glaciation. However, studies of the Antarctic, as well as other research concerning polar wandering, may eventually provide the answers. Certainly much has been learned about glaciation since the middle of the nineteenth century when Louis Agassiz (ag′a see), a Swiss-American naturalist, first recognized that continental glaciation had occurred. Agassiz had studied the behavior of glaciers in his native Switzerland. He learned to identify both erosional and depositional features of valley glaciers. When Agassiz visited the United States, he traveled across the northern states and recognized many features similar to those of his home area. He found widespread ground moraines, eskers, terminal moraines, and polished and striated bedrock in a region where no mountains were present. Following the theory of uniformitarianism (Section 6:1), Agassiz suggested that a massive ice sheet must have covered the northern United States. Many scientists have studied this region and have come to the same conclusion. The other behavior and features of existing glaciers help scientists to recognize the presence of glaciation in the past.

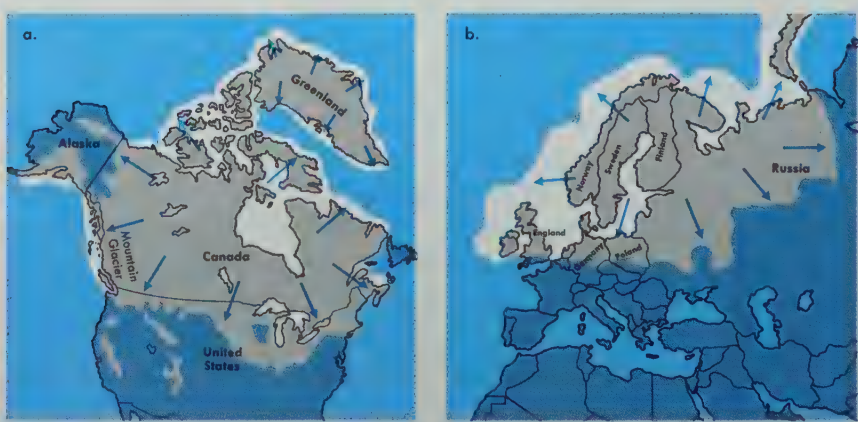

Figure 15-23. Only 11,000 years ago, millions of square miles of North America (a.) and Europe (b.) were covered by ice.

MAIN IDEAS

1. Snow becomes granular, firn, and finally true glacier ice if the thickness of ice is great enough, and if it remains in place for at least two seasons.
2. Snow collects in a snowfield and extends to the snow line where melting counterbalances deposits of new snow.
3. Glaciers form in high latitudes and/or high altitudes if precipitation is available and temperatures are below freezing.
4. Bottom ice of a glacier becomes plastic under pressure. Surface ice remains brittle and cracks when bottom ice begins to flow.
5. High altitude glaciers are called valley glaciers. High latitude glaciers that cover vast areas are called continental glaciers.
6. Glaciers erode by abrading with debris plucked from beneath them and frozen into the bottom ice.
7. Erosional features of valley glaciers include cirques, horns, aretes, U-shaped channels, and hanging valleys.
8. The Canadian Shield was covered by a continental glacier from about 1 million to 11,000 years ago.
9. Depositional features of glaciers include terminal moraine, ground moraine, drumlins, outwash plains, eskers, kames, kettle lakes, and finger lakes.
10. A continental glacier which covered part of North America apparently gouged out river valleys to form the present Great Lakes.
11. Ancient Lake Bonneville was present in Utah during the retreat of the continental glacier. Changes in climate caused this great lake to dwindle until all that remains is the Great Salt Lake.
12. Ice ages may result from a shift in the position of the earth's poles with respect to the continents, from changes in the atmosphere due to volcanic activity, or from changes in the amount of sun's radiation received on earth. More heat may have led to greater evaporation, more precipitation, and a filtering of the sun's radiation. Less heat may have led to an increase in the accumulation of ice.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

cirque	meltwater	recede
crevasse	moraine	shield
firn	piedmont	striated
granule	pluvial	terminal

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Erosion by glaciers covers more area than erosion by any other agent.
2. The snow line is the line where melting counterbalances addition of snow.
3. Glaciers form in mountains if snow reaches a depth of 100 ft to 200 ft and stays in place for at least two seasons.
4. Temperature and precipitation determine the formation of glaciers.
5. An ice field is not a glacier until the ice begins to move.
6. Movement of ice is most rapid where the ice is thickest.
7. Some material in a ground moraine may have been deposited by meltwater.
8. The outwash plain is formed by meltwater alone.
9. The Finger Lakes of New York State were formed by moraines left in their valleys by former glaciers.
10. The Great Salt Lake is a remnant of Lake Bonneville.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Formation of true glacier ice resembles the formation of (*igneous, sedimentary, metamorphic*) rock.
2. An ice cap covers much of (*Canada, Greenland, Ireland*).
3. The hollow in which a mountain glacier starts is called a(n) (*cirque, bergschrund, arete*).

4. Openings or cracks between rock walls and glaciers on mountain summits are called (*bergschrunds, aretes, horns*).
5. Sorted material deposited by meltwater is called (*drift, till, striated boulders*).
6. When melting exceeds forward movement, the glacier deposits a (*lateral, terminal, ground*) moraine.
7. Small hills composed of drift and left on the ground moraine are called (*kettle lakes, drumlins, cirques*).
8. Before the last continental glacier melted, the Great Lakes drained into the (*Hudson Bay, St. Lawrence River, Mississippi River*).
9. At one time, the Great Lakes covered much more of the area of (*New Jersey, Pennsylvania, Michigan*) than they do today.
10. The last ice age began about (*6, 2, 1*) million years ago.

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Rounded granules of ice become compacted by pressure into __?__ or __?__.
2. Valley glaciers are also called __?__ or __?__.
3. A glacier at the foot of a mountain is called a(n) __?__ glacier.
4. Erosion of the tops of hills indicates that the area was once covered by a(n) __?__ glacier.
5. Tributary glaciers leave __?__ above the main glacier channel.
6. The farthest advance of a glacier is marked by a(n) __?__.
7. Melting of buried blocks of ice leaves __?__ lakes in a glaciated area.
8. Ground moraine may contain small serpentine hills of sorted material called __?__ or rounded gravel hills called __?__.
9. The glaciated area of Canada is known as the __?__.
10. __?__ is the term that describes a rainy climate.

D. How and Why

1. What determines the erosive capability of a valley glacier? How does this differ from the erosive capability of a river?
2. Why might exceedingly low temperatures make the formation of a glacier impossible?
3. Why is the snow line at a higher altitude in the Rocky Mountains of Montana than in the Cascades of Washington even though these mountains are located in almost the same latitude?
4. Would you expect a greater snowfield on Mt. McKinley (elevation 20,320 ft) in Alaska, or on Mt. Chimborazo (elevation 20,551 ft) in Ecuador? Why?
5. Why does a continental glacier move in areas of little or no gradient?
6. How might the melting of ice caps affect sea level and the seacoasts?
7. How might melting of ice caps affect the circulation of seawater and climates of seacoasts?
8. How might melting of the ice caps change the altitude of continents?
9. Why was the drainage pattern of the Great Lakes changed after the last continental glacier melted?
10. How are the salt water bays (fiords) of Norway related to glaciers?

INVESTIGATIONS

1. (a) On an outline map of the world, indicate the present position of ice caps and glaciers.
   (b) On a map of the United States, indicate the present drainage pattern of the Great Lakes. Using a different colored pencil, show them before the glacier melted and the present drainage pattern developed.
   (c) On a map of North America, show the area covered by the last glacier (Pleistocene).
2. Examine the ice in the freezing compartment of a refrigerator. What kinds of ice do you find there? How are they formed?

3. (a) Report on any military bases which are located on an ice cap. Discuss the problems of living under glacial conditions.
   (b) Report on any story (fact or fiction) which tells of an animal or person being frozen in a glacier or ice cap.
   (c) Report on the life of Louis Agassiz and his study of glaciers.

INTERESTING READING

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* Well-illustrated material.

Wind

Wind erosion is neither as widespread as water erosion nor as deeply abrasive as glacial erosion. However, wind is an important erosional agent in climates and areas where water and ice are not abundant.

Unlike the flow of water and of valley glaciers, wind is not confined to channels. Instead, wind blows freely over the landscape in all directions and at varying speeds. But little erosion occurs unless the wind has material with which to abrade and undercut the obstacles in its path.

16:1 *Wind-Borne Material*

Wind includes large wind systems and local turbulent air movements.

Wind carries in suspension or sweeps along before it materials which cause wind erosion. Recall that large-scale air movements and currents are caused by temperature differences between the equator and the poles of the earth. The direction of the air movements is affected by the earth's rotation, as well as by temperatures. These movements constitute the major wind systems of the earth. (Section 10:2.) Although wind moves forward constantly, it also moves in a turbulent fashion, with updrafts, downdrafts, and local eddies.

Winds transport any available detritus, particularly from desert and shore zones.

Wind-borne, or **eolian** (ee oh′lee an) **material**, is composed of sand, silt, and dust particles picked up from the surface over which the wind blows. Plowed fields, river flood plains, volcanoes, and glaciated areas furnish rock debris, or *detritus* (di triet′us), to the wind. Deserts and shore zones where loose material is available and water action is intermittent are the most common sources of wind-blown deposits. On the other hand, moist areas and lands covered by vegetation contribute little material to the wind.

Most sand grains carried by the wind are quartz. But some grains are gypsum such as the White Sands of New Mexico. Other grains, such as the "coral sands" of Bermuda, are calcite. Volcanic ash or glass, finer than either quartz or gypsum grains, is also carried by the wind. *Loess* (les), the fine material carried by the wind, consists of silt-size particles and dust gathered from deserts, alluvial plains, or glaciated areas, especially from old, dry glacial lake beds.

Loess is composed of silt and dust-size particles.

Turbulent action carries the sediments at varying heights and in many directions. If the wind is gentle, heavy grains bump along the ground and bounce other grains out of place. These dislodged grains then can be moved easily by the wind. Sometimes grains are picked up by strong winds and are carried forward until the pull of gravity or a downdraft overcomes their forward movement. At times, blowing sand appears to form a moving blanket near the ground. Sometimes ground currents form miniature whirlwinds, called "dust devils."

Distance and height at which material is carried depend upon the size of the grains, the velocity of the wind, and the length of time the wind blows. The upper range of wind action is limited by the height to which the wind can toss the grains it carries. Because it is heavier than dust, sand stays close to the ground and falls quickly. Updrafts carry fine silt and dust into the upper air currents where strong winds can transport them far from their place of origin. Study of eolian deposits may furnish clues to ancient climates and geologic formation.

Wind action depends on size of grains, speed of wind, and period of time it blows.

Regardless of the type of material, wind is constantly redistributing loose sediments. In the process, the wind etches (ech′es) and cuts surface rocks and, thus, makes more fragments available as its tools of erosion.

Phyllis G. Lewis

Figure 16-1. White dunes in the background are deposits of gypsum at White Sands, New Mexico.

Figure 16-2.

EXPERIMENT. Obtain various types of detrital material, including clay, fine sand, and a mixture of gravel and sand. Arrange each type of material in a separate flat pan. Fill a fourth pan with damp sand and a fifth pan with damp clay. Direct a stream of air from an electric fan, a hair dryer, or a vacuum cleaner blower onto each of the pans. Be sure that the distance between the blower and the pan is the same for each test. Note what happens to each type of material. Now vary the distance to the blower. Then change the angle at which the air strikes the materials in the pans. Put obstacles (a few twigs, some gravel, a pencil, etc.) in the pans and observe the effect on the material. Sift some sand in front of the blower. What happens? If you use a hair dryer, what effect does time have on the behavior of the damp sand and damp clay? Why?

Record your observations in your notebook. What type of material is picked up most easily by the wind? What is the effect of moisture on the ability of the wind to pick up materials? How does an obstacle affect the action of the wind? What effect does the gravel have on the wind erosion of the sand-gravel mixture? What shape of dune did you form? What effect would vegetation have had on the experiment? In which pan(s) were dunes formed? If dunes were not formed in all pans, explain why.

16:2 *Erosion*

Wind erosion removes loose topsoil in semihumid and semiarid lands.

Removal of material by wind is called **deflation.** It is an important process in wind erosion. In semiarid and semihumid lands, wind removes tremendous amounts of topsoil in periods of drought. During the 1930's, parts of the bared land in the drought-stricken Middle West became known as the "dust bowl" because of the enormous quantities of wind-blown sediments. Cultivated land, no longer held in place by vegetation, lost more than three feet of topsoil. Some fine silt was carried as far east as the Atlantic Coast. Larger grains often came to rest in the source area and buried trees, houses, fences, and barns under worthless sand. Eventually, all of this wind-blown material came to rest. But the land laid bare by erosion was of little value for many years.

Wind erosion in deserts may leave bare desert pavements or oases at water table level.

Loose material may be removed so completely in desert areas that bedrock or a "desert pavement" of flat pebbles is exposed. Occasionally, the wind erodes material down to the water table. When water is available near the surface, trees, shrubs, and grasses take root and form an *oasis* (oh ae′sis), or fertile green

Soil Conservation Service Photo

Figure 16-3. A typical dust bowl scene in which wind has piled sand and silt around all obstructions.

spot within the desert waste. The trees act as a barrier against further erosion or additions of materials to the oasis. But occasionally, during especially severe storms, sand dunes may encroach on an oasis and bury it. Oases demonstrate how extremely fertile deserts may be where water can be provided.

Abrasion by wind polishes resistant rock and carves out soft layers. Wind caves, natural arches, rock windows, and bridges result from the sandblasting type of wind action. Even rock faces are etched into lace-like surfaces. Boulders left in the path of the wind are polished, etched, and planed into flat-sided rocks quite unlike the rounded shapes of water-worn pebbles. Desert boulders and pebbles that are too large to be carried by the wind have flat sides which meet at sharp angles. Each surface facing the wind is worn down to a flat side. As the boulder is turned, or the wind direction changes, other sides are also flattened and the rock becomes angular.

Small particles, such as sand, which can be carried by the wind develop spherical, pitted surfaces. Unlike water deposited sand, eolian grains have collided so often that all angles have been chipped away and the sand consists of uniform spherical grains. Water-borne grains are protected from one another by a thin film of water that clings to each grain. Below pebble

Figure 16-4. Ventifacts are shaped by the abrasive action of wind-blown sand.

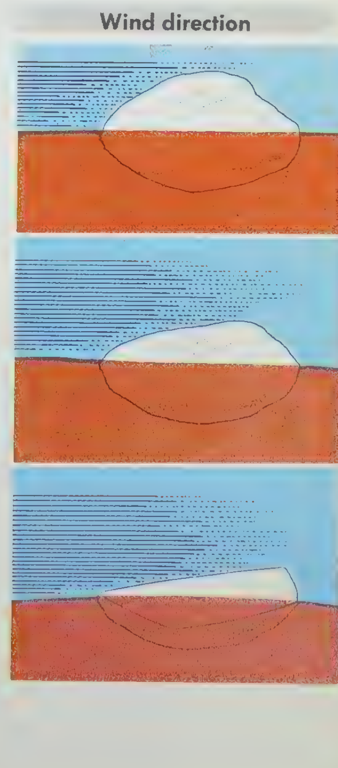


Figure 16-5. Weathering and erosional processes have combined to form these unique rock shapes in the Arizona desert.

size, particles carried in water tend to remain almost angular, and their surfaces are clear. Geologists can distinguish eolian fragments from fluvial fragments by their shape and surface appearance.

16:3 *Wind Deposits*

Wind-blown material comes to rest when winds die down. Sand bumps and bounces along the ground, and comes to rest near the place where it was picked up by the wind. Silt, the largest particles which wind can carry in suspension for any distance, is moved farther than sand and deposited separately. Fine dust particles may be carried great distances and for long periods of time, and be deposited only during rain or snow storms.

Loess may be gathered from alluvial plains, glacial deposits, or deserts.

Loess consists of particles so fine that they have retained their angular shape and tend to lock together to form densely packed soil. Loess is a fertile soil because it retains minerals that would be dissolved and removed by water. Sources of loess may be old glacial lake beds, alluvial deposits, or extremely fine desert material. In North America, loess deposits are found on hilltops and valleys near the Mississippi River. These deposits probably originated in glacial lake clays, or perhaps on the outwash plains of the last Ice Age. Fine material was carried down into the Mississippi Valley by strong winds blowing across the remains of the ice sheet. Winds re-sorted the material and left silt near the Mississippi River. Fine clay particles were

carried beyond the Mississippi Valley. In China, loess deposits are even thicker than those of the Mississippi Valley. They consist of wind-borne material brought from the Gobi (goh′bee) Desert and the Ordos (ohr′dohs) Desert.

Sand dunes are the most common wind deposits. Dunes form in semiarid and desert regions and on shore zones where sand is plentiful and dry. Coastal dunes form parallel to the shore; desert dunes form crosswise, or *transverse*, to the wind direction. Coarse sand is piled relatively close to its place of origin; fine sand may be blown some distance. Any obstacle in the wind's path slows its velocity and causes it to deposit its load. Since obstacles need not be large to produce this effect, small plants often start the growth of dunes. (Figure 16–6.)

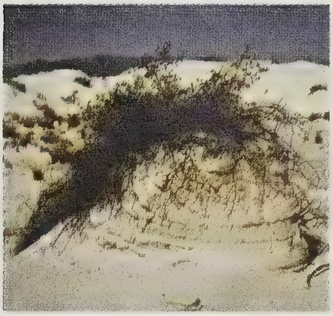


Figure 16-6. Vegetation on dunes helps to hold the sand in place and prevent migration.

Photos From Ward's National Science Establishment, Inc.

Along shores or in semiarid regions, plants may take root in the piled sand. Then the loose sand, which once threatened to bury everything in its path, becomes a fixed dune. Such grass- and tree-covered ridges, which once were migrating dunes, have formed parallel to the shores of some of the Great Lakes. Unanchored dunes continue to migrate inland along neighboring shores.

Figure 16-7. Dead trees show the destructive effect of the advance of a sand dune into the forest area.

If the wind's path is not obstructed, dunes move in the direction toward which the wind is blowing. Bare, hard surfaces are swept clean and every available particle of sand is added to the growing dune. Each wind scours sand from the windward side of the dune and carries it across the crest to the leeward side. This leeward slope is called the *slipface*, because loose sand slips and slides down its steep face. Eventually, the pile on the slipface becomes too high for the steep angle, and sand slides down in a thin sheet. Forming and re-forming of the piled sand results in a transverse dune with a gentle slope on the windward side and a steep slope on the leeward side. Dune shapes may be changed from time to time as the direction of the wind changes. Rounded, symmetrical dunes may form, but they tend to shift from place to place. Such dunes do not reach the height of dunes in a prevailing wind belt. (Figure 16–8.)

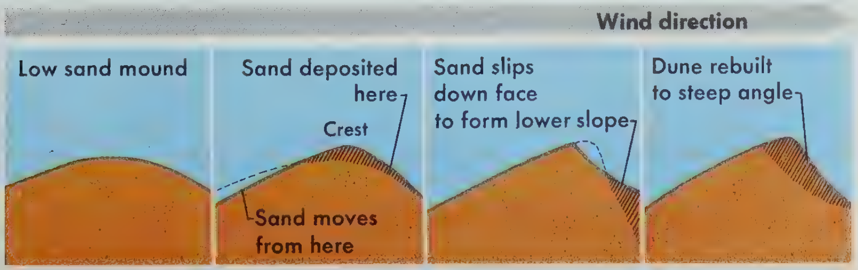
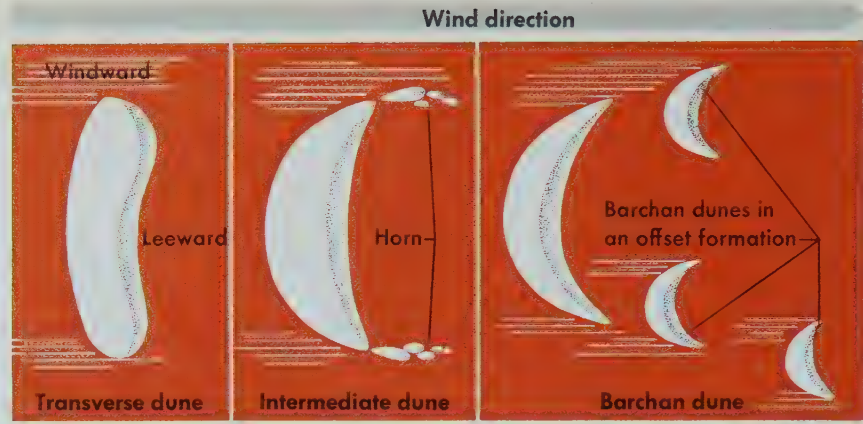


Figure 16-8. Dunes advance leeward as sand is blown from the windward slope over the crest to the slipface.

Figure 16-9. Transverse dunes are fashioned into barchans if the sand supply is limited.



Free moving dunes form barchan dunes with a convex side toward the wind.

Transverse dunes form on a hard, dry surface where wind direction is constant. Commonly, transverse dunes become crescent (kres′ent) shaped, or *barchan* (bahr′kahn), *dunes.* As winds continue to blow, sand from the ends of the growing dune is carried forward into horn-like projections. The convex side of the dune is toward the wind. Because the inside curve is protected on all sides but one, the slipface is steep. Over long periods of time, migrating sand is carried from the ends, and new barchans appear near the projections in an offset pattern. (Figure 16–9.)

Anchored dunes form parabolic dunes with a concave side toward the wind.

Another crescent-shaped dune, called a *parabolic* (par a bahl′ik) *dune*, is formed in a prevailing wind belt if vegetation holds down the end of a transverse dune. Winds move the central part of the dune forward into a concave curve. If the wind continues to blow steadily, the center of the dune may be carried away and later re-formed as a new dune.

American Airlines

Figure 16-10. The ripple marks and steep slipfaces of the dune show the prevailing wind direction to be from left to right. The movement of the dune has been halted by the rocky cliffs on the right.

16:4 Evidence of Eolian Erosion

Etched rock faces, polished boulders, wind caves and windows which appear where no fluvial or glacial erosion could have taken place are evidence of wind erosion. Rounded grains and excellent sorting by size distinguish wind-borne debris from that carried by water or glaciers. Migrating dunes or fixed dunes composed of unconsolidated sand grains are ample proof of the continuing work of the wind.

Eolian erosion is recognized by characteristic rock formations, etched boulders, and rounded rock fragments.

Evidence of past wind erosion and deposition is found in hardened sand dunes. Dunes which formed millions of years ago were covered and cemented into hard sandstone layers. Such dunes are recognizable by their cross bedding, in which the layers lie at steep angles to each other. Unlike the horizontal stratified layers of most sedimentary rock formations, eolian deposits are laid down with a gentle slope on the windward side and a steep slope on the leeward side. Although successive layers are composed of rounded grains of uniform size, shifts in wind direction are registered by layers laid down at different angles. Road cuts and renewed erosion have exposed ancient dunes in many parts of the arid and semiarid West.

Petrified sand dunes are wind deposits of ancient geologic periods.

Ward's Natural Science Establishment, Inc.

Figure 16-11. This cross section shows how a dune is built up layer upon layer.

MAIN IDEAS

1. Wind is movement of air in large systems, in local turbulence, in any direction, and at any velocity.
2. Wind erosion is particularly common in arid, semiarid, or shore zones where detritus is available. Plants help to keep materials from being carried away by the wind.
3. Wind-borne materials are quartz, gypsum, volcanic, or calcite sand, dust, and silt.
4. Size of grains, velocity of wind, and length of time wind blows determine how high and how far detritus can be carried.
5. Wind removes topsoil in semihumid and semiarid lands and may sweep desert surfaces down to hard rock layers or to water tables. Oases form where the water table is exposed.
6. Wind abrasion removes soft rock to form windows, leaves resistant rock in arches and bridges, etches boulders, and smooths and sorts sand grains.
7. Deposits of silt and fine clay derived from glacial lake beds, alluvial plains, or deserts form compact soil called loess.
8. Sand dunes form transverse to the wind with a gentle slope facing the wind and a steep slope away from the wind.
9. Migrating dunes may be barchans with a convex side toward the wind or parabolic dunes with the ends anchored and the center concave to the wind.
10. Eolian erosion creates abraded rock, spherical sand grains, and petrified sand dunes.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

barchan	eolian	oasis
concave	fluvial	parabolic dune
convex	loess	slipface
detritus	migrating dunes	transverse dune

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Wind erosion is not as widespread as water erosion.
2. Winds blow in the direction of the large wind systems.
3. Winds commonly blow in a turbulent fashion.
4. Sand grains are seldom lifted aloft except by strong winds.
5. "Dust devils" are miniature whirlwinds.
6. Dust storms of the 1930's originated in the fertile farms of the Mississippi Valley.
7. Eolian sand grains are angular and of many different sizes.
8. A crescent dune concave to the wind results if vegetation grows on the dune ends.
9. Shore dunes develop parallel to the waterline.
10. Winds which constantly shift direction produce parabolic dunes.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Wind-borne material is called (*fluvial, pluvial, eolian*).
2. Sediments deposited by water are (*fluvial, pluvial, eolian*) sediments.
3. Most common sand grains are (*gypsum, quartz, calcite*).
4. Bermuda's white beaches are grains of (*gypsum, quartz, calcite*).
5. China's large deposits of loess came from (*glacial deposits, deserts, alluvial plains*).
6. A crescent dune convex to the wind is a (*barchan, parabolic, transverse*) dune.
7. Migrating dunes commonly begin as (*barchan, parabolic, transverse*) dunes.
8. The dune which usually has the steepest slipface is the (*barchan, parabolic, transverse*) dune.

9. The gentle slope of a dune is on the (*windward side, leeward side, slipface*).
10. Loess deposits in the Mississippi Valley are mainly from (*glacial lake deposits, desert dust, fluvial deposits*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. A general term for rock debris from weathering and erosion is __?__.
2. Wind deposits of dust and silt are called __?__.
3. During droughts, cultivated lands may lose __?__ which is no longer held in place by vegetation.
4. The wind cuts and __?__ rock surfaces.
5. A small grove of trees and shrubs in a desert is called a(n) __?__.
6. The steep slope of a sand dune is called the __?__.
7. Crescent dunes convex to the wind are called __?__.
8. The White Sands of New Mexico are deposits of __?__.
9. Fine silt and dust are removed from deserts by the process of __?__.
10. Irregular __?__ in certain sandstone layers may indicate that the layers belong to ancient hardened sand dunes.

D. How and Why

1. Do all ocean shore zones have sand dunes parallel to the coast? Why?
2. Why can the wind sort material so completely that sand and silt are seldom found together?
3. Why do particles of loess retain their angles, but sand grains become rounded?
4. Why are sand dunes along the eastern shore of Lake Michigan larger and more prevalent than sand dunes on the western shore of Lake Michigan? Why do the Michigan and Indiana dunes migrate inland?
5. Why are "dust devils" more common in southwestern deserts than in northern, sandy areas?

6. In what type of rock are wind caves and windows formed? Why?
7. How could you recognize a hardened sand dune?
8. Why do Great Sand Dunes of Colorado and White Sands of New Mexico remain localized instead of migrating?
9. Dust from the eruption in 1883 of the volcano Krakatoa in Indonesia is said to have been carried around the entire world. How would this have been possible?
10. Would quartz, gypsum, or calcite particles be most effective for wind scour and abrasion? (Refer to Table 4–2.)
11. Explain why telephone poles, light poles, etc., in desert regions are protected by piles of boulders around their bases, but this protection does not extend upward beyond one to two feet.

INVESTIGATIONS

1. Report on wind blown volcanic ash from the volcano Irazu in Costa Rica (1963-64) or Mt. Katmai in Alaska (1912).
2. Report on the effect of the "dust bowl" of the 1930's. Discuss the conditions that existed, reasons for the conditions, and possible safeguards against their repetition.
3. Report on the effect of wind on Cape Cod, Cape Hatteras, and Padre Island on the Gulf Coast.
4. On a world map, indicate all desert regions and all known loess deposits. Relate the deserts to major wind systems and land features.
5. Report on the sand dunes of the Great Lakes, Southern California, and Colorado. What are the problems created by these dunes? How can they be controlled?

INTERESTING READING

Bendick, Jeanne, *The Wind*. Chicago: Rand McNally & Co., n.d.

*Leopold, A. Starker, *The Desert*. Life Nature Library. New York: Time, Inc., 1961.

*Shimer, John, *This Sculptured Earth, The Landscape of America*. New York: Columbia University Press, 1959.

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* Well-illustrated material.

Crustal Movements

Winds, rivers, glaciers, and ocean waves have eroded the surface of the earth since its formation. Yet mountains still reach toward the sky, and continents remain above the sea. What forces maintain mountains and continents and offset the effects of weathering and erosion?

Ancient Greeks and Romans believed that mountains were formed by giants who were trying to reach the heavens. According to one myth, the giants piled one peak on top of another to form a stairway to the sky. Zeus, the king of the gods, struck down the peaks with his thunderbolts and scattered the remains into rugged, inaccessible mountain chains. Zeus then imprisoned the giants beneath the mountains. During their struggle to escape, the giants broke the earth's crust and hurled liquid rock against their enemy, Zeus.

17:1 *Diastrophism*

These Greek and Roman myths are not acceptable scientific explanations for upheavals of the earth's crust or for eruptions of volcanoes. But the myths show that ancient peoples recognized some relationship of these events to the interior of the earth. Today, many scientists believe that most crustal movement, or *diastrophism* (die as′tra fiz em), is caused by the release of heat energy during the decay of radioactive elements within the earth.

Diastrophism includes all processes by which rocks are broken, folded, uplifted, or depressed.

Mountains display rocks of every kind in every possible position. Rock formations may be horizontal, twisted, torn, tilted, or folded. Geologists go to mountains to study the relationships among different rock layers. From such studies, they hope to understand the processes by which rocks are moved from one position to another.

Diastrophism includes all processes by which rocks are moved from one place to another or from one position to another. The term diastrophism comes from a Greek word which means "to deform, or twist." The effects of diastrophism are most evident in sedimentary rocks. Changes in position can be recognized because sedimentary rocks are laid down in layers in nearly a horizontal position. Sedimentary rocks that are found in mountains or plateaus thousands of feet above the sea are evidence that uplift has occurred. Sedimentary rocks that lie in a horizontal position at high levels show that movement must have been vertically upward. Rocks that are folded, twisted, or broken, reveal that movement must have been not only in a vertical direction, but also in other directions.

Deformation can be recognized in sedimentary rocks that were laid down in horizontal layers at sea level.

Horizontal movement from one place to another may be recognized if rock layers end abruptly, then reappear some distance away. When houses, fences, and other man-made installations attached to solid rock are broken and the parts are separated, the rocks must have shifted.

Figure 17-1. Majestic peaks of the Grand Teton Mountains, Wyoming, represent a series of fault blocks tilted downward toward the right.

Ned Schreiner

Uplift and subsidence often can be recognized where shore features are above or below present sea level.

Even slight crustal movements may be observed along shore zones. Beaches and undercut cliffs high above the present water level suggest a previous upward movement of the land or a lowering of sea level. Flooded river mouths, known as *estuaries* (es′ cha wer eez), suggest either a downward movement of land or a rise of sea level in the past. Sometimes it is impossible to determine whether land has risen or sea level has lowered. Movement measured as the difference between the old and new positions of certain features is known as *relative movement.*

Evidence of alternating uplift and *subsidence* (sub sied′ ens), or sinking, of a shore zone is found in a temple near Naples, Italy. The temple was built on land above sea level. Eventually, the land sank, and underwater clams bored holes in the marble columns of the temple. Today the temple is again above sea level, and the clam borings can be seen halfway up the temple columns. The old temple has a record of the subsidence and uplift of the Mediterranean shore bored into its marble columns.

Few records of crustal movement can be recognized as easily as the one in the temple at Naples. But examples of displacement are found in many areas. The *San Andreas* (san · ahn drae′ahs) *fault* is a line of weakness along the Pacific Coast

Figure 17-2. In the Panorama Hills, northeast of Maricopa, California, drainage is offset to the right where streams cross the San Andreas fault. Movement along the fault is toward the northwest on the southwestern side of the fault.

U.S. Forest Service

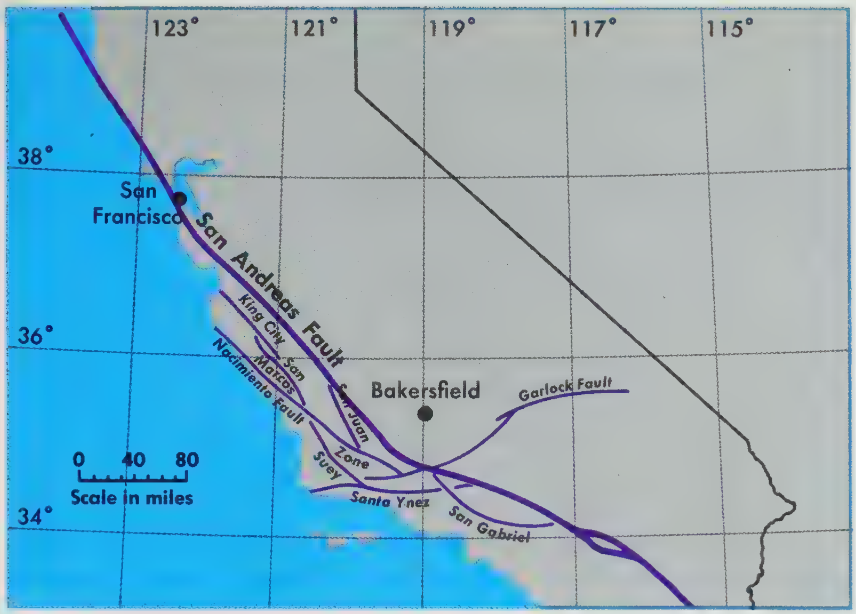


Figure 17-3. The San Andreas strike-slip fault accounts for many earthquakes as the oceanward block moves northward from time to time.

where many earthquakes have occurred. During the San Francisco earthquake in 1906, horizontal movement along the San Andreas fault measured between 16 ft and 21 ft. Along the Baltic Sea, measurements which have been recorded for many years show that the coast is rising at the rate of about 1 in./yr. The direction of crustal movements may be upward, downward, or horizontal. Displacements may occur rapidly and require only a few seconds for several feet of movement or they may occur slowly and require thousands of years for a few inches of change. Regardless of the direction or rate of crustal movements, any change in rock position is outward evidence of the work of internal forces.

Movement still occurs along the San Andreas Fault in California.

17:2 *Internal Forces*

Materials within the earth, like other solids, hold together, or cohere (koh hir′), because of the mutual attraction between molecules. This cohesion, or molecular resistance to change in shape or volume, is called **cohesive force**. External force must be exerted against a solid body to cause a change in shape or volume. *Elastic bodies* recover their original shape and volume when the external force is removed. But every body has a limit of resistance to force. If this limit is exceeded, the body changes shape or volume, or both, and does not return to its original shape or volume. A force that permanently changes the shape or volume of a given body exceeds the *elastic limit* of that body.

Such forces may be of several kinds. Among the forces that cause diastrophism, or crustal movements, are tension, compression, shearing, and buoyancy. (Figure 17–5.)

Tension is a stretching force which may pull rocks apart.

Tension (ten′chun) is a pulling force. A body under tension is stretched, or pulled in opposite directions. Tension is illustrated by the stretching of a rubber band. When tension is removed, the rubber band returns to its original shape and size because it is elastic. But even the elasticity of a rubber band is limited. A rubber band breaks if it is stretched beyond its limit of elasticity. Rocks also are elastic. But if the tension is greater than their elasticity, rocks will pull apart. In general, rocks tend to have great strength, and their elastic limit is exceeded only by forces of great magnitude.

Compression is a squeezing force that may cause bending or breaking.

In contrast to tension, **compression** is a system of forces pushing against a body from directly opposite sides. For example, a soft rubber ball may be compressed or squeezed until it changes from a sphere to an elongated shape. The rubber ball tends to return to its original shape when the compressional forces are removed. Rocks also change shape when squeezed or compressed. However, rocks are less elastic than rubber and tend to retain their changed shape or volume. Rocks may even break if they are compressed beyond a given point. Compression tends to squeeze rocks into accordion-like forms that occupy less space than their original shapes.

Shearing forces are directed against a body from two directions. But the opposing forces are not directly opposite the same point of the body. Shearing causes bodies to become twisted or torn, or to be broken in such a way that parts of the body slide past one another. Many rocks of the earth are sheared during crustal movements.

Figure 17-4. Stresses within the earth cause movement of the crust and often rupture rocks along lines of weakness.

Buoyancy is an upward force exerted by a liquid on a floating or submerged body. The force is always equal to the weight of the displaced liquid. A body that is less dense than a liquid will float in that liquid. Some vertical movements of the earth's crust are due to buoyancy. Great crustal blocks float on the plastic, pliable mantle (density 3.3 g/cm^3) as blocks of wood float on water. Blocks composed only of sedimentary rock (density about 2.5 g/cm^3) float higher than blocks composed of granite (density 2.7 g/cm^3) or blocks composed of basalt (density about 3.0 g/cm^3). Actually, blocks of the crust may contain more than one kind of rock, but continental rocks are mostly granite and oceanic blocks are mostly basalt. During erosion, material is removed from the elevated blocks of the continent and deposited in great deltas along the seacoast. As the continental blocks are reduced in weight, they tend to float higher on the mantle. But beneath the delta, the added weight causes the crust to sink, or subside. This state of *equilibrium* (ee kwa lib′ree um), or balance, among blocks of the earth's crust is called **isostasy** (ie sahs′ta see).

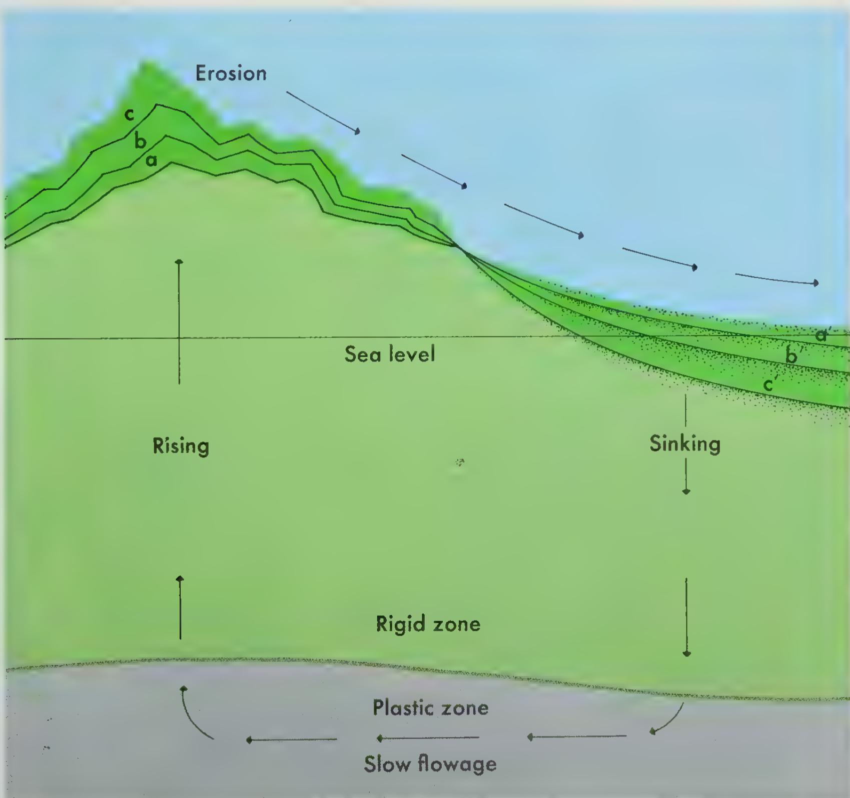


Figure 17-5. As layers *c*, *b*, and *a* are removed by erosion and deposited to form layers *c′*, *b′*, and *a′*, the mountain rises and the sea floor sinks.

Figure 17-6.

EXPERIMENT. *Fill a durable plastic bag with water and tie it tightly. Press on the bag. What happens to its shape? How does this illustrate isostasy? What happens when you release the pressure?*

EXPERIMENT. *Float two blocks of wood in a pan of water. With a grease pencil or crayon mark the water line on the sides of the pan and on each block. Add some sawdust or pencil shavings on top of one of the floating blocks. Is there any change in the water level? With another color, mark the new water line on the pan and on the block with another color. What do the blocks of wood represent? What does the water represent? How does this experiment illustrate isostasy?*

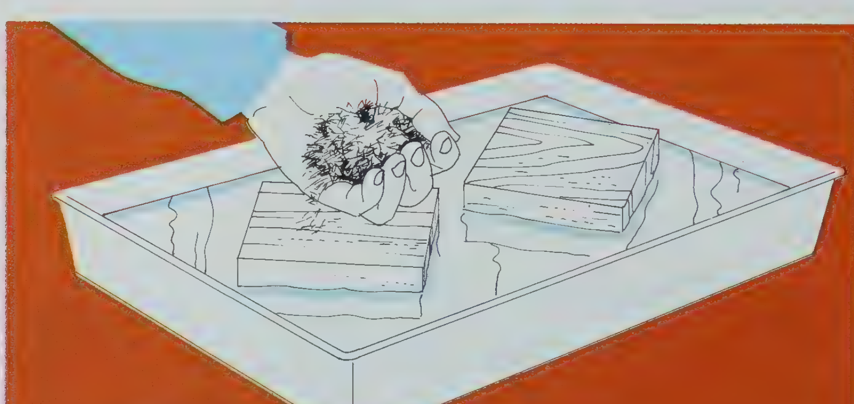


Figure 17-7.

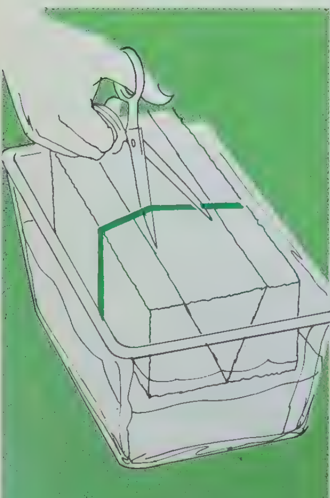


Figure 17-8.

EXPERIMENT. *Cut an inverted triangle from the center of a 9-in. x 5-in. x 3-in. block of styrofoam. (Figure 17–8.) Hold the parts of the block together with a rubber band. Float the block in a plastic or Pyrex loaf-cake pan no larger than 10 in. x 6 in. x 5 in. (If you use a larger pan, use a larger block so that there is only 1 in. clearance on each side.) Cut the rubber band on the floating block. Carefully observe what happens.*

Determine the density of the styrofoam. Measure a block of styrofoam and determine its volume. Float it in water and measure the volume of styrofoam that is below the water line. The block will sink until it just displaces its own weight in water. Since the density of water is 1 g/cm^3, the density of the styrofoam will be the weight of the block divided by the volume of the block. To determine the specific gravity of the styrofoam, its density must be divided by 1 g/cm^3, the density of water. Suggest another way in which the volume of the displaced water can be determined.

Origin of the force of buoyancy within the earth is more easily explained than the origin of other forces. But the effects of these other internal forces may be observed on the earth's surface, and scientists have offered a number of hypotheses to account for these effects.

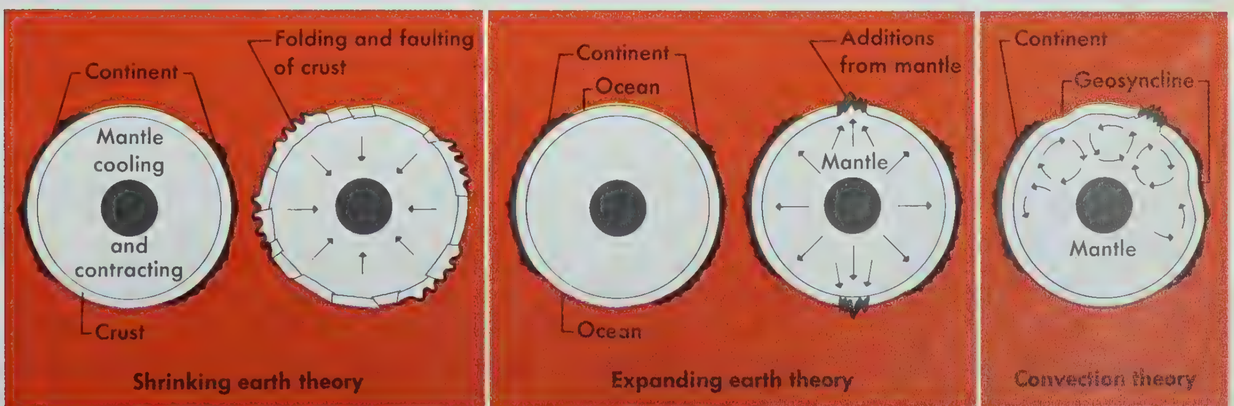
The **shrinking earth theory** suggests that the earth originally was much hotter than it is now. Cooling probably began in the crust, and now extends to about 500 mi below the surface. Within the zone of cooling, contraction of the materials causes tensional forces to develop. These forces cause the crust to adjust to the shrinking upper mantle by buckling and wrinkling like the skin of a drying apple.

Earth's internal forces result from its unequal heating and cooling.

The **expanding earth theory** proposes that heat from the decay of radioactive elements is accumulating within the earth. As the heat increases beneath the crust, the earth expands and cracks its outer layer. The great rift zone (Section 11:4) in the ocean basin has been cited as evidence for the expanding earth theory and for the shrinking earth theory.

Another explanation is called the **convection theory**. According to this idea, radioactive elements are distributed unequally within the mantle. An excess of heat develops where radioactive elements are most abundant, and rocks in this region soften, expand, and flow upward. Recall that convection currents are present in the atmosphere (Section 10:1) and in the ocean (Section 12:1) due to excessive heating at the equator. Convection currents within mantle materials receive heat from radioactive decay instead of from the sun. But the currents rise, cool, move horizontally and then downward, like those of the air and the ocean. In the mantle, horizontal convection currents may oppose one another and cause compression. As they

Figure 17-9. Mountain building is attributed to stresses that originate beneath the crust. Various theories have been developed to account for these stresses.



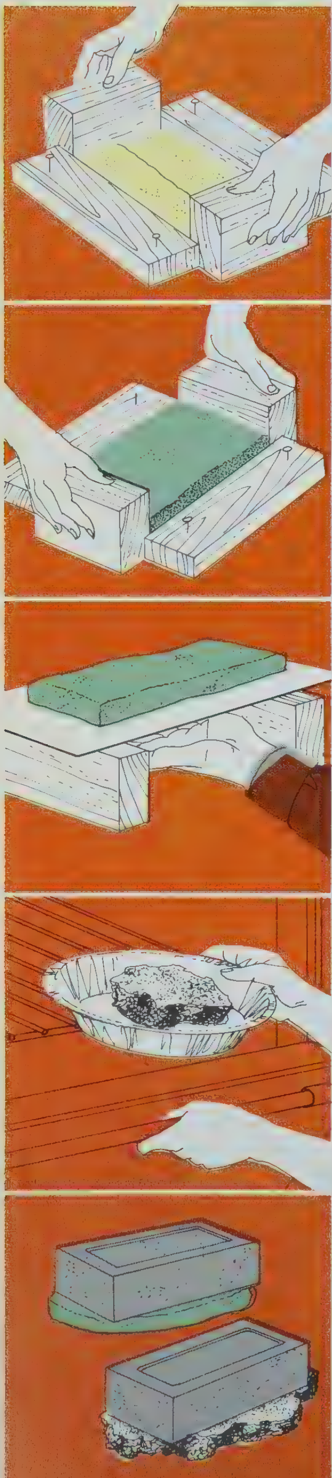


Figure 17-10.

move upward or downward, they may cause tension or shearing in the crust. Theoretically, ascending and descending currents oppose the cohesive forces in the solid crust and cause crustal movement.

None of these proposed hypotheses is entirely satisfactory. More knowledge is needed about the mantle before internal forces can be explained fully. However, the effect of the various forces on the position of rock layers is evident, although the exact origin of the forces is not known.

EXPERIMENT. Arrange a slab of "silly putty" and one of plasticene or modeling clay between two blocks of wood so the slabs cannot spread sideways. With two other blocks of wood, push against the slabs until they buckle. Is there any difference in the way the silly putty and the plasticene clay react to pressure?

Mix clay and water into a thick, rather dry mass, and mold it into a brick. Allow the brick to dry. Then put it between two blocks of wood so it cannot spread sideways. Push against the brick with the other two blocks of wood. What happens?

Now put a piece of heavy cardboard on two blocks of wood with a space between them. Moisten some clay and fashion it into a brick. Place it on the cardboard above the space between the blocks. Now push vertically upward on the cardboard until it bends. What happens to the brick? Repeat with modeling clay on the cardboard. Is there any difference in the way modeling clay and the clay brick react to pressure? What is the effect of moisture on clay?

Put a piece of hardened road tar in a pan in an oven (250°F) for a few minutes. Remove the tar and describe any changes that occurred. Strike the tar a sharp blow with a hammer. Does it break? Now put the same piece of tar in the refrigerator freezing compartment for several hours. Remove the tar and strike it with a hammer. What happens? What conclusions can you draw about the effect of heat and the effect of pressure on the state of matter?

Place a square of modeling clay on a table. Put a heavy weight on the clay for one or two hours. The surface of the weight should have nearly the same dimensions as the clay. What happens? Put a heavy weight on the hardened tar. The surfaces should be nearly equal. Leave the weight on the tar in the refrigerator overnight. What happens? Leave the weight on the tar in a warm room overnight or in the sun for a few hours. What happens?

17:3 Rock Structures

Structure refers to the position of rock layers. Tensional, compressional, and shearing forces cause changes in the position or structure of rocks. Most sedimentary rocks originally were deposited in a horizontal position at or near sea level. But, like a layer cake, sedimentary rocks consist of different layers which may be recognized by differences in color, grain size, or kind of sediment. The upper or lower surface of each layer is known as a **bedding plane.** Bedding planes provide reference planes by which movement can be recognized. Because bedding planes originally are horizontal, if they are broken or bent, it is apparent that movement occurred after deposition.

Structure refers to the position of rock layers.

Structures differ according to the amount of force applied, the rate at which the force is applied, and the kind of rock that is subjected to the force. Many rocks yield to compressional or shearing forces by folding. If enough force is applied, eventually they may yield by breaking. Slowly applied compressional or shearing forces tend to bend rocks. The same amount of force applied in rapid blows tends to break rocks. Certain kinds of rock break more readily than other kinds. For example, limestone breaks more readily than shale. On the other hand, rock salt always flows when subjected to even a slight compressional or shearing force. At depth, rocks are covered by a great load of overlying material, and compressional and shearing forces cause bending rather than breaking. Near the surface, the same forces tend to cause rocks to break.

Rocks may bend, break, or move in any direction under sufficient pressure.

Because different kinds and amounts of force are applied against different kinds of rock, a great variety of structures occurs. Rocks may be broken into blocks. The blocks may remain stationary, or they may move up, down, or horizontally. Rocks also may be bent into gentle wavelike forms, or they may be folded until formerly horizontal bedding planes become vertical or upside down.

Figure 17-11. Pattern of joints in granite.

J. C. Russell, U.S. Geological Survey

Fractures in rocks are simple breaks in which no movement is involved. Fractures often have a rectangular pattern, known as a *joint system.* (Figure 17–11.) Most uplifted rocks are fractured. Basaltic flows commonly exhibit hexagonal fracture patterns that form during cooling and contraction.

Faults are breaks accompanied by movement. Some faults can be recognized because the rocks on one side of the break have been lifted or pushed upward to form sheer cliffs. Other faults occur within the crust and cannot be seen on the earth's

surface. Many faults have been discovered during the drilling of wells. Some faults on the ocean floor have been found by sounding devices. (Section 11:4.)

Movement along faults may result in complex patterns of rock distribution. Layers sometimes stop abruptly at the fault plane and then continue at some distance above, below, or horizontally from the position in which the layers normally would occur. Movement along the fault plane may be in any one direction, or in any combination of directions. Commonly, one side of a fault plane moves upward and the other moves downward, but some movement may be horizontal as well. *Fault blocks* are blocks of rock bounded on at least two sides by faults. Such blocks may be a few feet or several miles wide.

Fault planes may be nearly vertical, or they may be tilted at an angle less than 90°. Fault angles are measured between an imaginary horizontal plane and the plane along which movement occurs. Broken layers of rock may lie in a horizontal position, or may be tilted or folded.

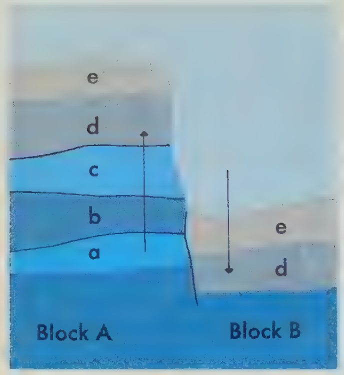


Figure 17-12. Block B has moved downward along a vertical fault relative to Block A.

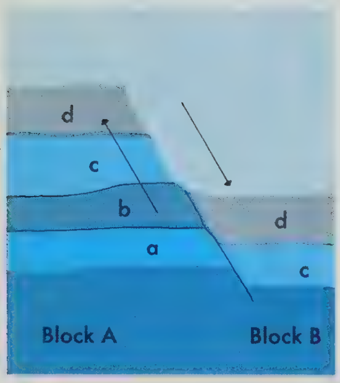


Figure 17-13. Block B has moved downward along a normal fault plane.

Figure 17-14. Block A has moved upward relative to Block B, and erosion has removed Bed *e*.

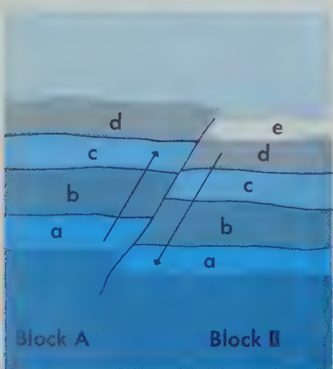


Figure 17-15. A normal fault in the Wasatch sandstone with downward movement on the left.

D. E. Winchester, U.S. Geological Survey

Folds are bends in rock layers. Most folding probably occurs below the surface of the earth at depths where heat has caused rocks to become pliable or plastic. When pliable rock is subjected to compression, it is bent into a new, shorter shape. Folds may require thousands of years to form. Gradually, rock layers change from horizontal positions to a series of alternating arches and troughs. (Figure 17–16.) Similar structures may be formed by squeezing an accordion. Arches are called *anticlines* (an′ti kliens); troughs are called *synclines* (sin′kliens). Folds may be a few feet or several miles wide. Folds may be squeezed together until the bedding planes are nearly vertical. Sometimes a fold is pushed over until it lies on its side. Complex folds may be broken by both fractures and faults. Tensional, compressional, and shearing forces form the complex structures associated with areas of mountain building.

Figure 17-16. Undisturbed layers of sedimentary rock are normally horizontal. When subjected to stress, they may be folded into a variety of shapes.

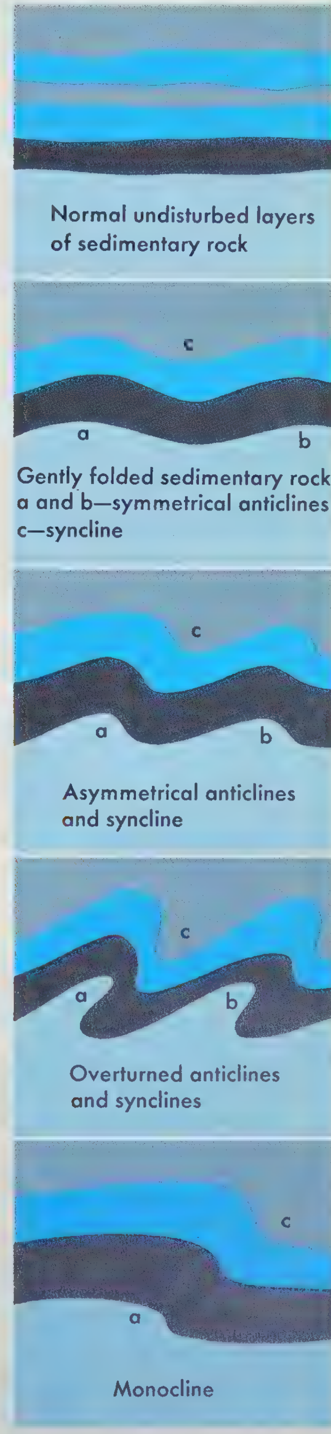
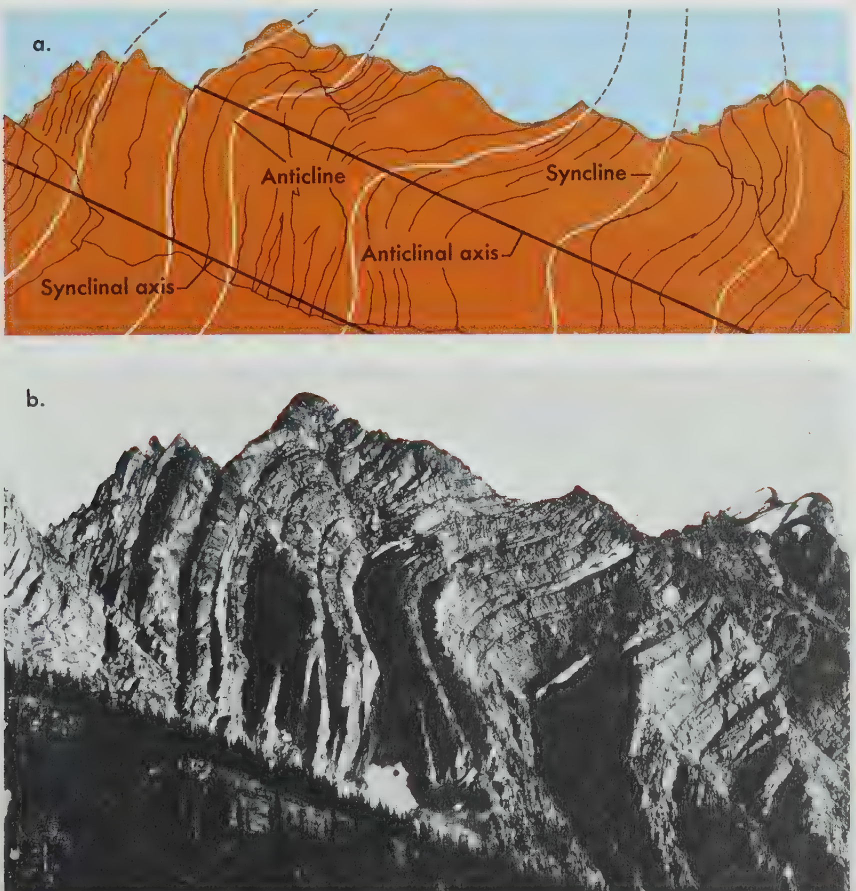


Figure 17-17. From the cross-sectional sketch (a.) it is evident that the sedimentary beds have been tilted to an almost vertical position during mountain building (b.).



U.S. Forest Service

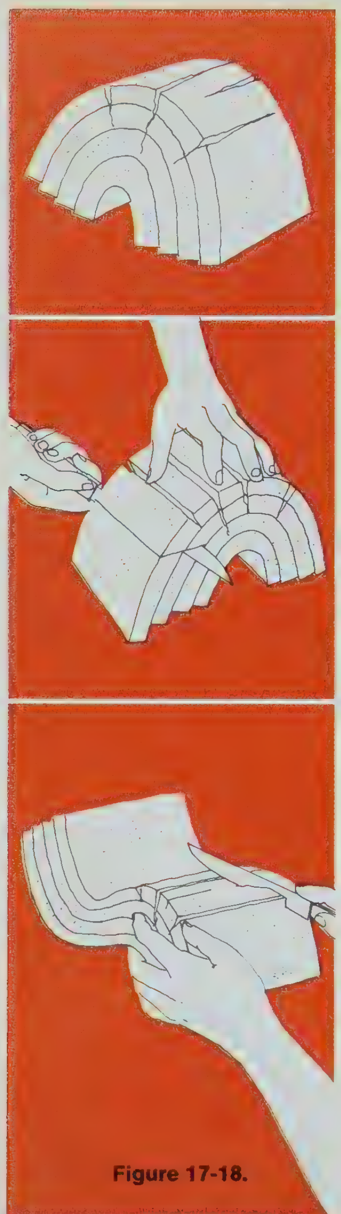


Figure 17-18.

ACTIVITY. In paper cups, make four different mixtures resembling shale, sandstone, conglomerate, and limestone. Use mud, sand, bits of rock or small pebbles, patching plaster, and water. Color three of the mixtures with cake coloring so they can be easily identified. Arrange the "sedimentary rocks" in layers on a cardboard base. Allow the rocks to dry, then push or pull them until you have illustrated folds, faults, and fractures. Cut through the folds and faults with a sharp knife so you can see them in cross section. Label the layers to indicate which is shale, sandstone, conglomerate, and limestone. Now bend a piece of plasticene clay into folds. Is the clay more resistant to bending than the sedimentary rocks?

Use several colors of plasticene clay to resemble different sedimentary layers. Fold the sequence into an anticline. If small cracks appear in the clay, do not be concerned; they are common in nature. When you have a fold, cut off its tip so that you can view several layers of your model. Now, on a sheet of paper, draw the layers as they appear from above. Add a legend to your map to indicate the order in which the beds were deposited. For example, blue—oldest layer; green—next older layer; red—youngest layer. From the distribution of beds as indicated on your map, how could you tell that the structure is an anticline? (Figure 17–18.)

Using at least three colors of plasticene clay, fold the layers into a syncline. Cut off the top so you can see all three layers when you look down on the model. Summarize your findings so that, with the aid of a geological map, you could recognize a syncline from the distribution of beds. What must you know about the beds to use this method?

With a sharp knife, cut vertically through the anticline and the syncline deep enough to show how the beds would look if a river cut across their surfaces. What are some differences between the modeling clay and your synthetic sedimentary rocks? Based on your answer, why do rocks fold instead of break? Why do some folds end in faults near the surface?

17:4 Structural Mountains

Mountain chains contain complex folds, fractures, and faults.

Mountain systems are great masses of nearly parallel rock ridges which rise sharply above the surrounding plains. Mountain systems include many kinds of mountains. Any part of the earth's surface that rises above the surrounding area is called either a mountain or a hill, regardless of its origin. *Mountains* rise 2,000 ft or higher above the adjacent area; *hills* have elevations of less than 2,000 ft. The major classes of mountains are structural mountains, produced by uplift; vol-


Bill Browning, Montana Chamber of Commerce

Figure 17-19. Absoraka Range, overlooking Yellowstone Valley near Livingston, Montana, is only a small part of the vast Rocky Mountain system.

canoes, produced by igneous activity; and dissected mountains, produced by erosion.

The great mountain systems of the world are roughly parallel to the continental coastlines. The width of a mountain system is measured in hundreds of miles; its length is measured in thousands of miles. Mountain systems exhibit every kind of diastrophism, every type of structural feature, and all stages of erosion. Rocks in mountainous regions include igneous, metamorphic, and sedimentary materials. Sedimentary rocks contain evidence of shallow water deposition in their fossils, ripple marks, and mud cracks. Most metamorphic rocks retain features that suggest a sedimentary origin. Igneous rocks include lava flows, and often dikes, sills, or even laccoliths of granites, diorite, or gabbro. Because they are difficult to cross, mountain systems have influenced the history of mankind. For example, in North America, the Appalachian Mountains lie parallel to the Atlantic Coast. Because of these mountains, early settlement was limited to the coastal region. The Rocky Mountains and Coast Ranges, which lie parallel to the Pacific Coast, are part of a mountain system that extends from Alaska through Mexico, and southward into the southern tip of South America. Early settlers of California came by sea, rather than by the difficult land route.

Although mountains rise above the plains and act as barriers to travel today, geologists believe that the main mountain building events occurred in areas that at one time were sinking troughs, or **geosynclines** (jee oh sin′kliens). Geosynclines form parallel to the coast. Early in their history, they may have been troughs at the base of the continental slope. Such troughs often mark the position of a major fault which extends downward through the crust and into the mantle. Geosynclines are large features–they may be several hundred miles wide and thousands of miles long. They may persist as sinking troughs for hundreds of thousands of years.

Thousands of feet of sediment from the continent and offshore volcanoes accumulate in a geosyncline prior to uplift.

Sediments are carried into a developing geosyncline from the continent on one side. On the oceanward side, volcanoes contribute material both as volcanic debris and as erosional products from volcanic islands. Eventually, thousands of feet of sediment and volcanic debris accumulate in a geosyncline. At the bottom of the trough, temperatures and pressures that cause metamorphism eventually are reached. Heat, produced by radioactive decay of elements, is prevented from escaping by the great blanket of sediments that fill the trench. Some materials melt as the temperature rises. Igneous intrusions move upward from the mantle to form great batholiths within the geosyncline. During this period, materials in the geosyncline are uplifted to form mountains. Crustal movements include vertical uplifting, folding, and faulting. Tensional, compressional, and shearing forces cause complex patterns to develop.

Magma may form at the bottom of a geosyncline if temperatures exceed the melting point of rock under pressure.

Intrusions of magma accompany the uplift of mountains from a geosyncline.

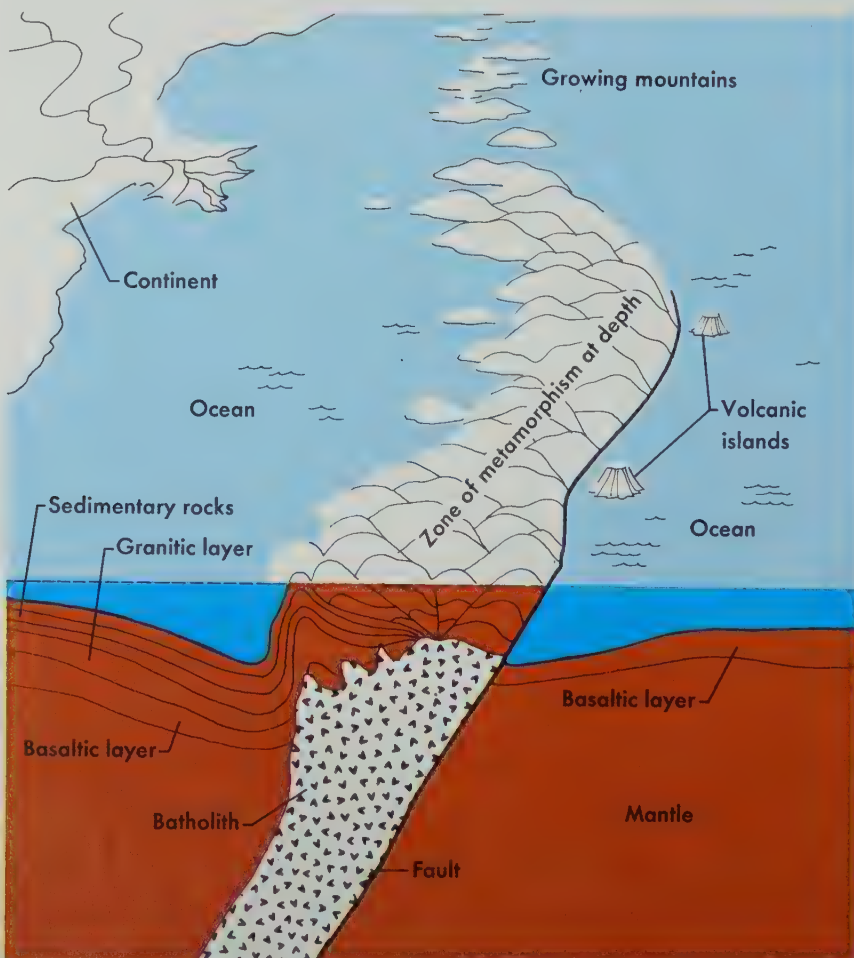


Figure 17-20. Great mountain chains eventually rise from geosynclines along the edges of continents.

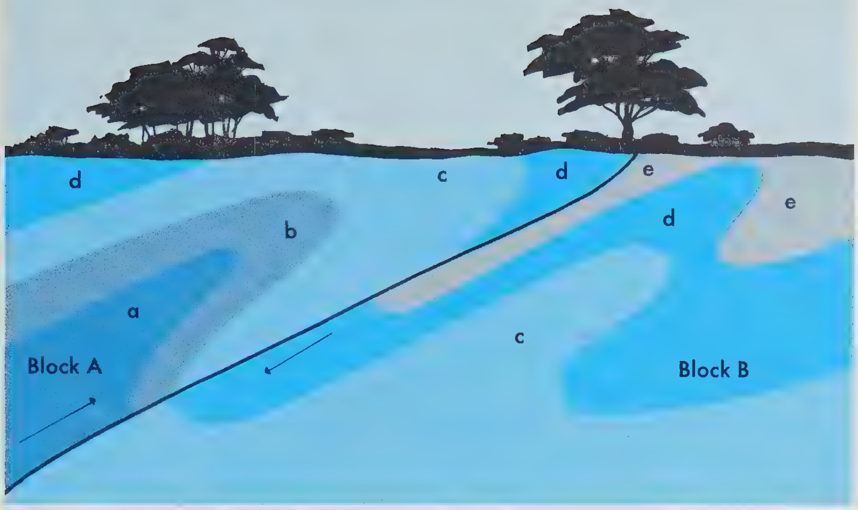


Figure 17-21. Many folds like this one are hidden beneath the surface, but topographic evidence of uplift is removed by erosion.

Processes involved in the uplift of mountains from a geosyncline are called **mountain building.** The complicated folded and faulted mountains that are formed are known as **structural mountains.** Mountain cores are areas of great uplift. They consist of great batholithic intrusions and metamorphic rock. Folds are complex and thrust faults are common. *Thrust faults* are breaks along which older rock may be pushed upward and over younger rock layers.

Volcanic activity, igneous intrusions, and metamorphism are characteristic of the mountain core.

As the distance from the mountain core increases, folds become less and less complex. Eventually, folds may disappear, and regions of relatively horizontal beds, elevated high above sea level, form a **plateau area.** A steep cliff, or *escarpment* (is kahrp′ ment), where rocks have been torn apart by tension, forms the border of a plateau. The uplift of mountains affects a continent far beyond the area of the mountain system itself. A plateau is one of the more visible effects of uplift. The Colorado Plateau of Arizona, New Mexico, Colorado, and Utah is associated with the Rocky Mountains. The Allegheny and Cumberland Plateaus of Pennsylvania, Kentucky, and Tennessee are plateau areas associated with the Appalachian Mountains.

Plateaus are uplifted regions in which sedimentary layers remain approximately horizontal.

Block fault mountains are another structural feature associated with regions of mountain building. As igneous rocks cool, they contract. Tension, which results from cooling, causes steep fractures to form. When movement occurs along these fractures, great crustal blocks may be raised or lowered. Mountains throughout Nevada, Utah, and parts of California are block fault mountains. Movement still continues along many of these crustal blocks.

17:5 Volcanic Mountains

Volcanic mountains are formed by surface eruptions of lava. Batholiths are formed by intrusions of magma that do not reach the surface.

Volcanic eruptions and lava flows usually occur in areas of mountain building, but volcanoes are found on plateaus as well as in mountain systems. Single or multiple volcanoes may form along the same fracture or fault. If lava contains large quantities of gas, volcanic eruptions tend to be explosive. Lava which is blown out of the *vent*, or opening at the summit of the volcano, cools quickly and forms cinders. Cinders pile up at the foot of the opening in steep *cinder cones*. If lava does not flow readily, dome-like volcanoes tend to form. **Dome volcanoes** are usually composed of rhyolite. Volcanic eruptions in which lava flows out quietly form **strato-volcanoes.** Strato-volcanoes are usually made of andesite, and are layered flows with gentle slopes. **Shield volcanoes,** like strato-volcanoes, are built up layer upon layer. However, shield volcanoes have a much wider base than strato-volcanoes. Shield volcanoes are formed of basalt, which flows readily and spreads over a wide area before it hardens.

Figure 17-22. A chain of small craters within the summit of Maui's Haleakala Volcano.

Hawaii Visitors Bureau

Paricutin is an explosive volcano built of cinders.

In 1943, a new volcano resulted from an explosive eruption in a field in Michoacan (mee cha wah kahn′), Mexico. This volcano, named Paricutin (pa ree ke teen′), erupted about one billion tons of ash, cinders, and bombs, or large fragments, during its first year. Bombs were thrown about 4,000 ft into the air. Today, Paricutin is a cinder cone volcano which rises 9,000 ft above sea level. Many years ago, a similar eruption formed the volcano called Sunset Crater, near Flagstaff, Arizona.

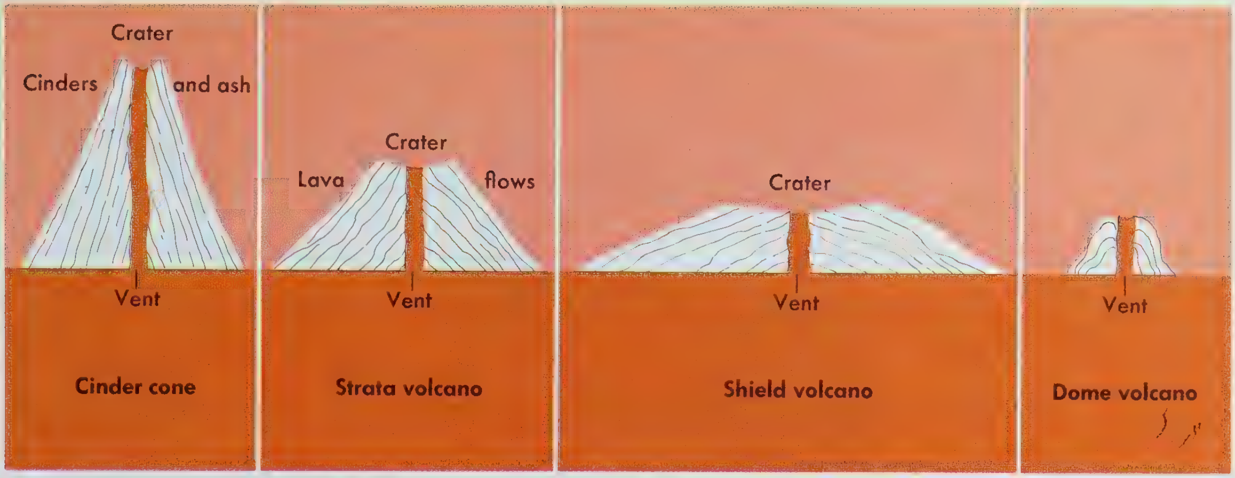


Figure 17-23. The composition of a volcano determines its shape. Free-flowing basalt forms a low volcano with a wide base; viscous lavas form high volcanoes on a relatively narrow base.

Mount Shasta, in northern California, is a strato-volcano formed by flows of andesite that accumulated to a height of 14,162 ft. Instead of explosive eruptions, lava welled up from a central vent and oozed out quietly, layer upon layer. Mount Shasta, which is associated with the mountain building of the West Coast, may have been active a few thousand years ago.

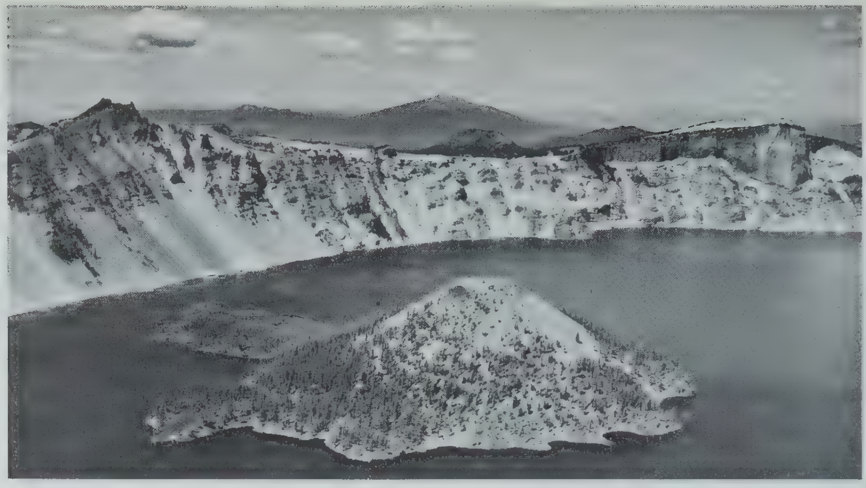
Hawaiian Islands are shield volcanoes built of layers of basalt.

If it were possible to view the Hawaiian Islands from the ocean floor, it would be evident that they are the peaks of a submerged major mountain chain. These volcanic islands erupted from five vents along a major fault line in the Pacific Ocean floor. Because basalt flows readily and spreads out, the Hawaiian Islands have the wide base common to shield volcanoes.

Figure 17-24. Basalt cools in many weird shapes as it pours down a steep slope.

W. C. Mendenhall, U.S. Geological Survey

Figure 17-25. Crater Lake, Oregon, fills the summit depression of an old volcano in which a young volcanic cone forms Wizard Island.



Oregon State Highway Dept.

Calderas are depressions at the summit of extinct volcanoes.

Most volcanic mountains have depressions at the summit called **craters,** or **calderas** (kal der′as). Some depressions are formed during a period of inactivity by collapse of volcanic debris into the vent. Other depressions result from a violent explosion which removes the top of the volcano. Some subsidence of the vent may also occur. Crater Lake, Oregon, now occupies the depression formed by an explosion in the summit of an extinct volcano.

EXPERIMENT. Set a metal funnel upside down in a deep pan that is one-quarter full of water. (A coffee percolator pipe also may be used.) Build a slope of modeling clay around the funnel, to the edge of the pan, but just below the rim, to allow space for water. Set the pan on a ring stand and heat it with a Bunsen burner. What happens? How is this model like a volcano or a geyser? What happens at great depths below the earth's surface where no openings are present? What are the possible effects of heating rock, or the fluids within the rock, so that melting occurs or steam forms? (Figure 17–26.)

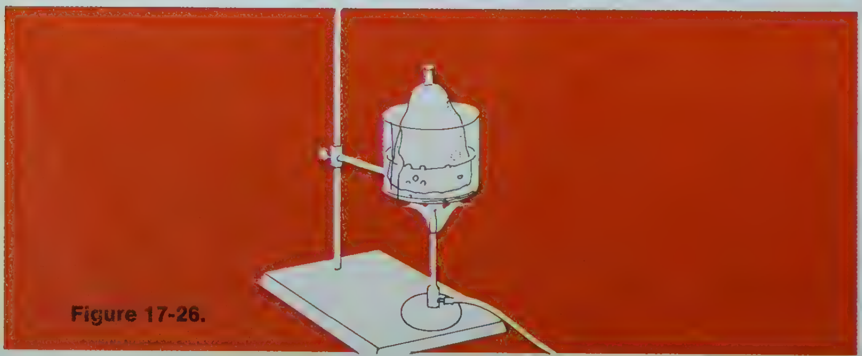


Figure 17-26.

17:6 Dissected Mountains

Volcanoes, block fault mountains, and mountains due to folding and faulting produce landscapes which contain various elevations. But landscapes may have a variety of hills, valleys, and even mountains that result from erosion instead of mountain building processes. Because they are high above sea level, plateaus are especially subject to erosion.

Many mountains and hills have been formed during the development of a drainage system. Rivers flow down slopes, cut channels, and remove material to form valleys. As the valleys widen, the region between them becomes a series of mountains or hills. These mountains or hills between valleys are higher than the surrounding area only because erosion has cut the valleys below the original height of the entire area. The resulting mountain summits represent the original elevation above sea level. Mountains and hills that rise above the valleys are known as **dissected mountains** because they have been dissected, or cut, from the original landscape. (Figure 17–27.) As the drainage systems are enlarged, they begin to erode even the summits of the mountains. Mountains become hills, and, eventually, hills become plains.

Plateaus eroded to form hills and mountains are known as **dissected mountains.**

Plateaus become noticeably dissected, but structural mountains also are subject to erosion. Anticlines often are stretched and broken at their crests. Valleys may form in the weakened crest of an anticline, leaving the adjacent syncline as a mountain when the anticline is eroded. Many synclinal ridges in the Appalachian Mountains remained after the adjacent anticlines were worn away. Valleys are eroded from soft, unresistant layers. Hard, resistant layers form ridges which extend high above the valleys. The ridges are called **cuestas** (kwes′tas) if the resistant layers slope gently. If the resistant layers slope steeply, the ridges are called **hogbacks.** Some dissected mountains are remnants of resistant igneous rock which was intruded into less resistant sedimentary layers. After weaker sedimentary rocks are removed by erosion, laccoliths and volcanic necks form isolated hills which rise above the surrounding plains.

Resistant rock layers may form cuestas and hogback ridges after nonresistant rock layers have been eroded.

Some mountains are rock that has escaped erosion. Other mountains are higher than adjacent plains because they have been pushed above their surroundings. Still other mountains consist of piles of debris poured, or blown out of vents, to form

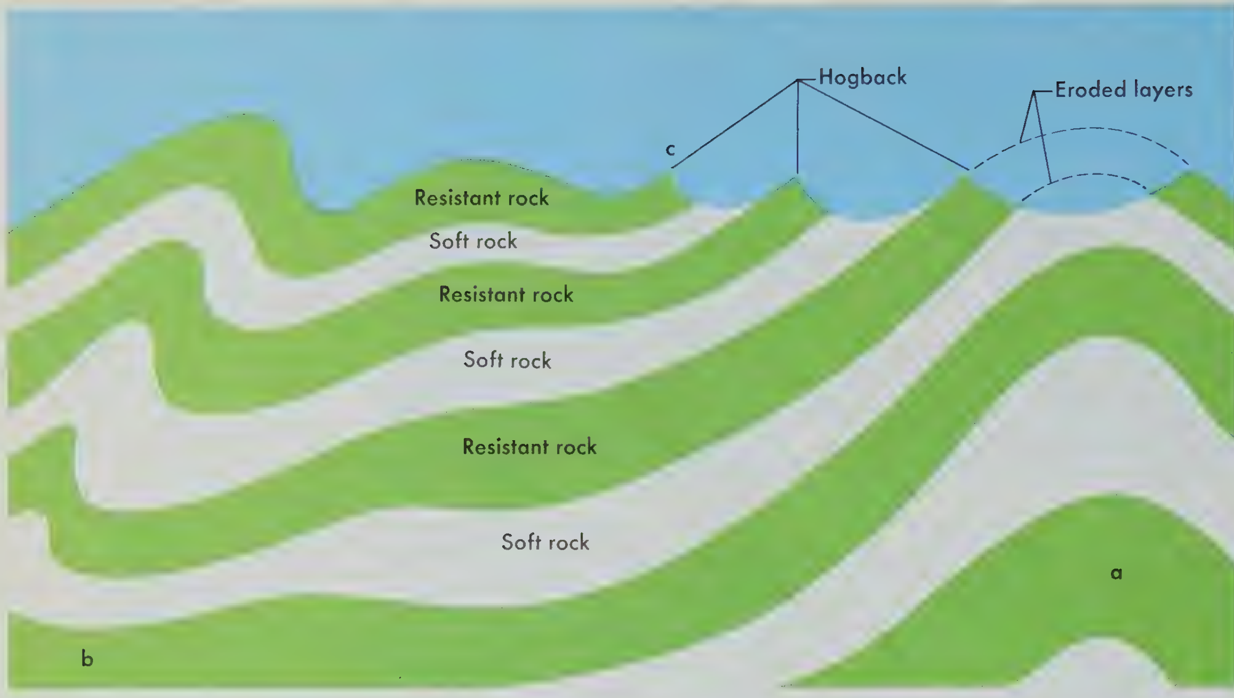


Figure 17-27. Erosion has removed a number of layers to form a valley at the crest of anticline *a*, but anticline *b* is still protected by the resistant layer that forms a hogback at *c*.

volcanoes. Each mountain or system of mountains was formed by one or more of these processes of diastrophism, igneous activity, or erosion. The kinds of rock, the amount of tilting, and the degree of erosion determine the history of mountains.

Figure 17-28.

ACTIVITY. Mold each of four colors of modeling clay into four slabs exactly 1 in. thick. Cut one slab into a circle that will just fit into the cake pan used in an experiment in Section 17:2. Cut the other slabs into circles with decreasing diameters. Pile them in the pan with the largest at the bottom and the smallest at the top, to represent a hill. Add water to the pan until the lower slab is covered. To make a map of the hill, look down on the cake pan. The first contour line is the line of contact between the water and the hill. To draw the line accurately, make an outline on paper that is the same size as the upper rim of the pan. Measure out from each corner of the pan to find the horizontal position of the point of contact between hill and water. Plot this position as a dot on your map. Take several readings from different points along the edge of the pan to the hill, and then join the dots to form a line. This line is a contour line. *It represents the line of intersection between a horizontal plane (the water) and the surface of the hill. If 1 in. of clay represents 100 ft, and if the bottom of the pan represents sea level, what is the elevation of this contour line? To determine the second contour line, add water until*

the second slab of clay is covered. Repeat the mapping procedure until you have completed the contour map of the hill. How many contour lines are there on your map? What would be the shape of the contour lines if you were drawing a depression instead of a hill? Assuming that each color of clay represents 100 ft, number the contours on your map. Why is there no 400-ft contour?

Now turn the hill over and set it in the pan. This time start with sea level; that is, the contact between the upper surface of the inverted model and water added to this level in the pan. Repeat the activity by removing water to the contact with the next lower slab. Remove the slab and draw contours at each of these depths. Using a scale of 100 ft, what are the numbers on these contours? Why are they negative numbers?

Assume that each color of clay represents a different layer of sedimentary rock. How would you describe the position of the layers in the original hill? Were they flat, horizontal, tilted, or sloping? Which of the layers was the oldest? Which layer was the youngest?

When you understand the principle of contouring, use the hill model to demonstrate the outcrop pattern of sedimentary layers that are more complex than those of the original model.

ACTIVITY. Use the hill and the pan from the preceding activity. Separate the layers of the hill, but do not change the outline. Carefully shave off part of the surface of the bottom layer so that the thickness is ¼ in. on one side, but 1 in. on the other side. Do the same with the second layer, and put them together with the thin part of the second layer above the thick part of the first layer. Do not change the third layer. On the fourth layer, make channels similar to erosion channels. These channels should extend down the entire hill, as a river channel or a gulley would. Now repeat the procedure outlined in the preceding activity. But this time, mark the cake pan in inches and add water first to the 1-in. line, 2-in. line, and so on. Draw the contours as directed before.

Refer to your map and to the hill in the cake pan and answer the following questions. Does the presence of the channels affect your contour lines? If not, why not? Do the channels affect the pattern of the water? In the preceding activity, the height of the water indicated not only the contact between different colors of clay, but also the position of the surface of the hill. Is this true in this activity? Do the surface contours or the topographic contours show the positions of the rock layers? Could you draw contours to show the positions of the rock layers?

Figure 17-29.

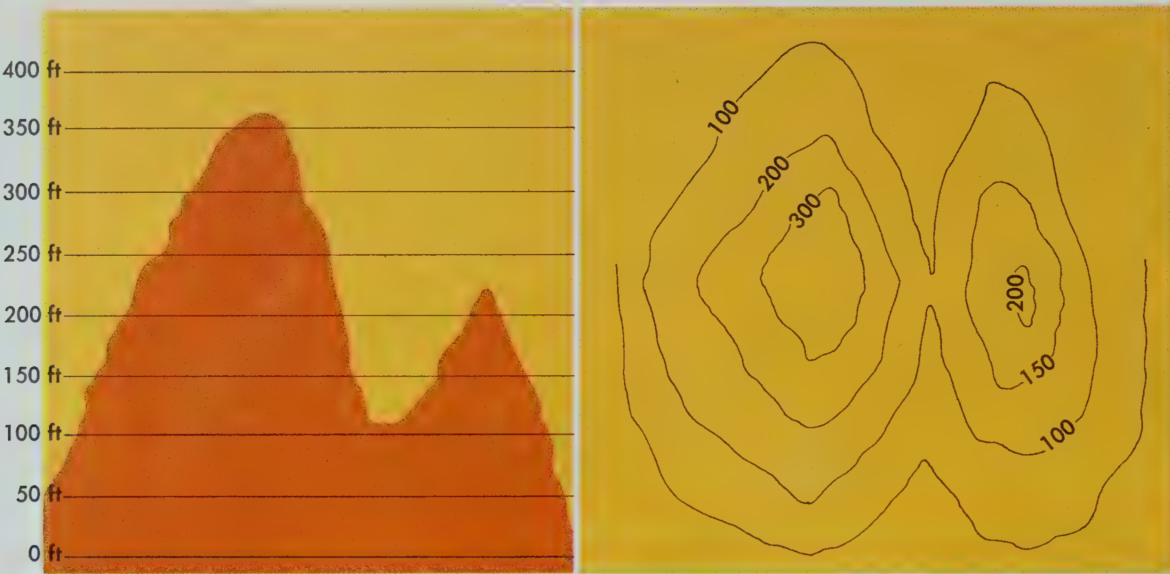


Figure 17-30. On the right, contour lines show the elevation of the hills shown in profile on the left.

Figure 17-31. Hingham Bay, Hull, Mass.
Scale 1:31680 Contour Interval 10 ft

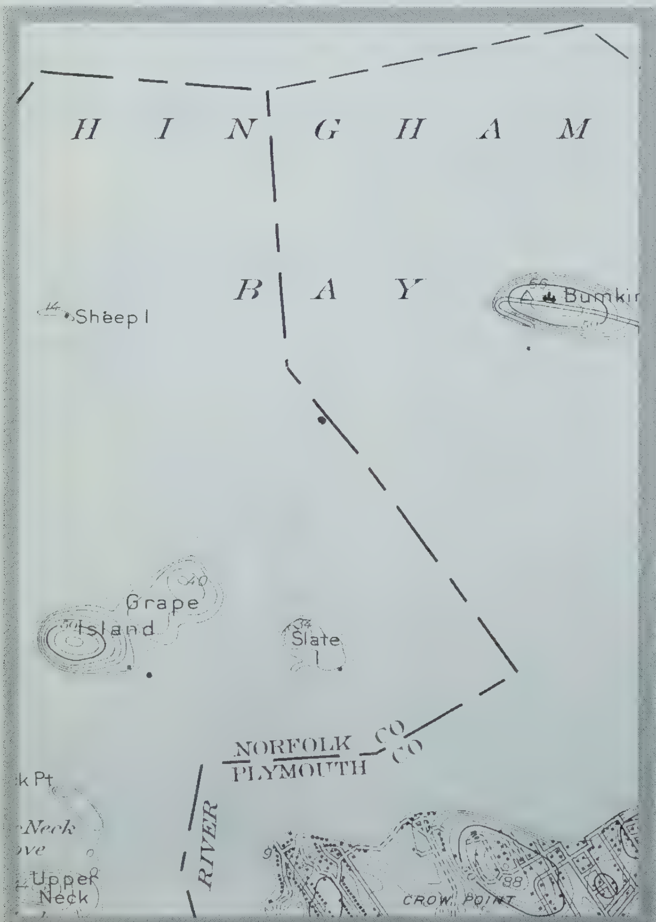


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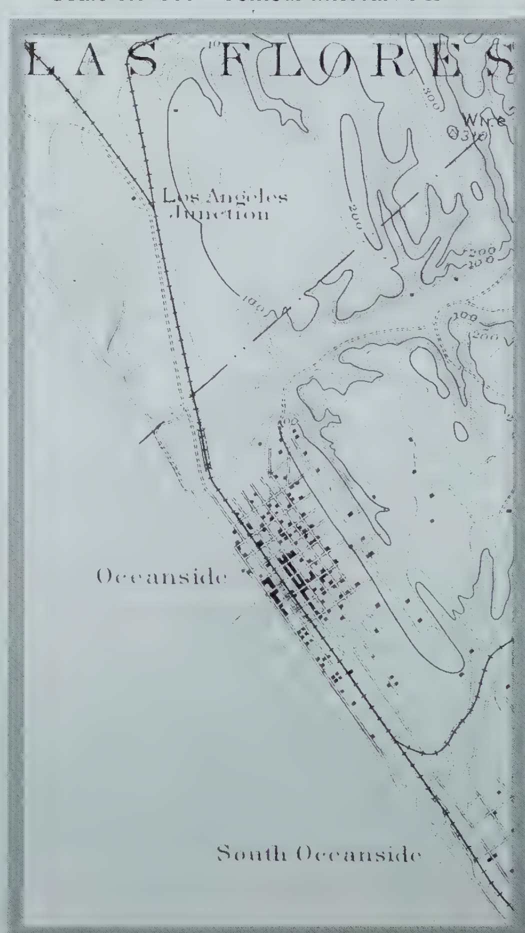
Figure 17-32. Oceanside, Calif.
Scale 1:62500 Contour Interval 25 ft



U.S. Geological Survey

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Figure 17-33. Mammouth Cave, Kentucky Scale 1:62500 Contour Interval 25 ft

U.S. Geological Survey

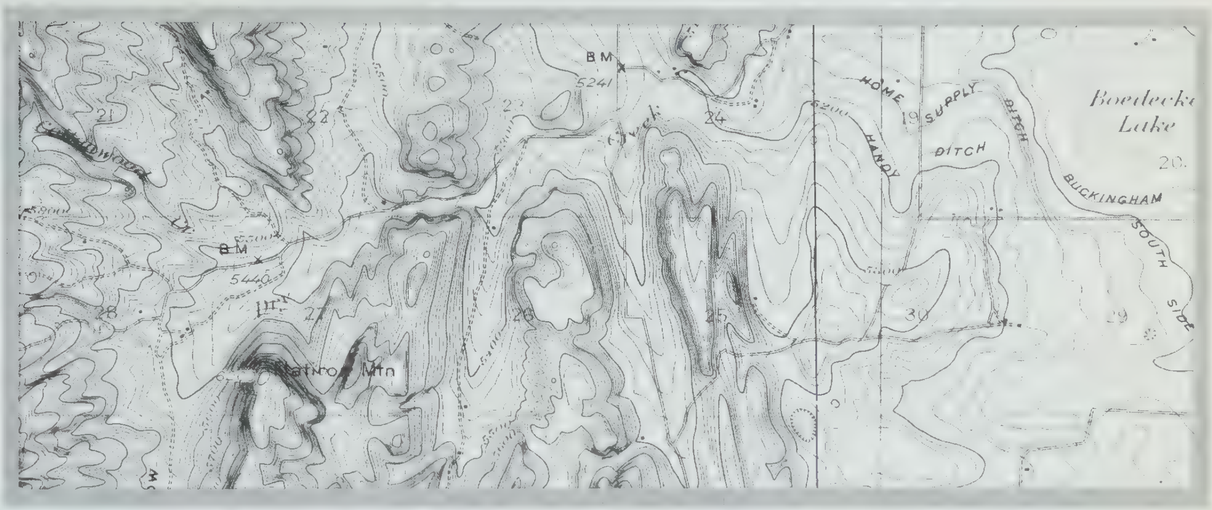
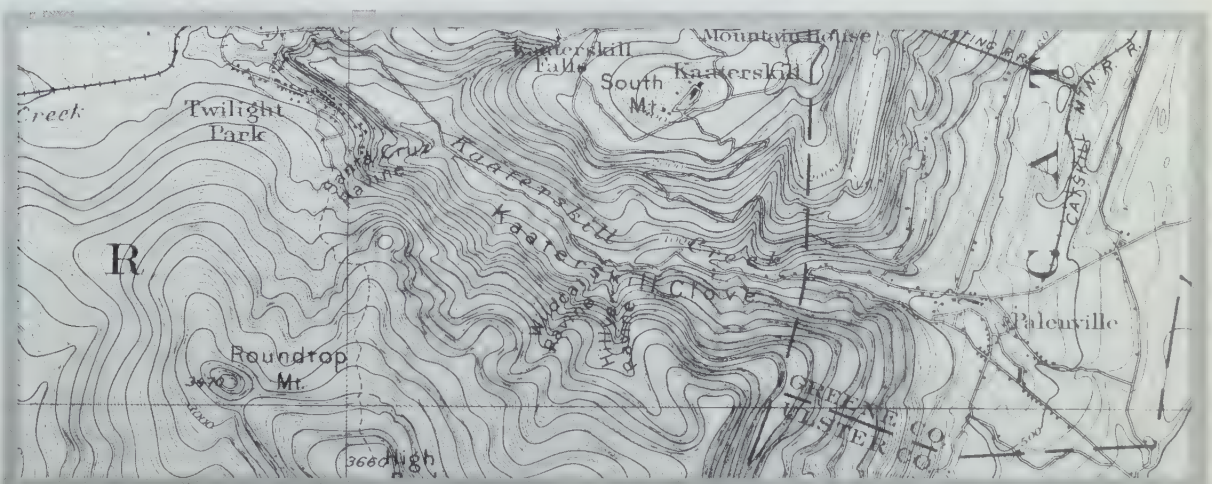


Figure 17-34. Loveland, Colorado Scale 1:62500 Contour Interval 20 ft

Figure 17-35. Kaatersill, New York Scale 1:62500 Contour Interval 20 ft

U.S. Geological Survey



MAIN IDEAS

1. Many geologists believe that decay of radioactive elements in the earth's interior is the major cause of diastrophism.
2. Sedimentary rocks, which were laid down in horizontal layers, exhibit diastrophism in twisted, broken, and uplifted layers. Shore zones serve as a reference point for relative movements.
3. Vertical movements of the earth's crust due to buoyancy maintain a state of isostasy.
4. Internal heating or cooling causes tension to pull, compression to push, and shearing to twist rocks and distort their positions.
5. Some scientists believe diastrophism is caused by cooling and shrinking in the outer layers of the earth. Others believe that crustal movements are caused by heating and expanding. Still other scientists theorize that heating causes convection currents in the mantle to displace rocks of the crust.
6. Structural changes in rock layers depend upon the amount of pressure, how long or how suddenly the pressure is applied, and the kind of rock involved.
7. Rock fractures become faults if movement occurs along the fractures.
8. Mountain chains contain every type of rock and structure. Mountains develop from geosynclines which lie adjacent to and parallel to coastlines of continents. The greatest diastrophism occurs on the oceanward side of the geosyncline. The least diastrophism occurs on the continental side of the geosyncline.
9. Volcanic mountains include cinder cones, strato-volcano, dome, and shield types. Paracutin is a cinder cone, Mt. Shasta is a strato-volcano, and the Hawaiian Islands are shield volcanoes.
10. Plateaus of the earth are regions that are raised vertically but which escape intense folding and faulting during mountain building. Plateaus are on the continental side of a mountain chain.
11. In time, erosion dissects plateaus into hills and mountains. Mountains and hills are eventually eroded into plains.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

anticline	escarpment	isostasy
caldera	estuary	plateau
compression	fault	shearing
crater	folds	subsidence
diastrophism	geosyncline	syncline
dissected mountains	hogback	tension

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Diastrophism is believed to be caused by decay of radioactive elements in the earth's matter.
2. Movement along the San Andreas fault illustrates block faulting.
3. Shearing of rocks causes tremendous twisting.
4. Melting of glaciers causes uplift.
5. Expansion of the earth's crust accompanies cooling in the mantle.
6. Structures are influenced by the kind of rock involved.
7. Brittle rocks tend to fold rather than break.
8. Deeply buried rock layers tend to break rather than fold.
9. Mountain ranges commonly appear near to and parallel to the continental coastline.
10. The Hawaiian Islands are examples of shield volcanoes.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Crustal movements are most easily recognized in (*igneous, sedimentary, metamorphic*) rock.
2. Rocks which are bent into troughs are called (*anticlines, synclines, block faults*).

3. According to the theory of (*isostasy, diastrophism, convection*), buoyancy of crustal blocks may result in uplift.
4. According to the (*shrinking earth, convection, expanding earth*) theory, decay of radioactive elements causes rising and descending currents in the mantle of the earth.
5. A joint system occurs in rock layers which have simple (*folds, faults, fractures*).
6. A break in a rock combined with either upward or downward movement is called a (*fault, fold, fracture*).
7. A huge, sinking trough developed off a coastline and parallel to it is a (*syncline, anticline, geosyncline*).
8. Slow-moving, widespread layers of lava form a volcano known as a (*cinder cone, strato-volcano, shield volcano*).
9. The abrupt, steep-sided, continental-facing edge of a plateau is a(n) (*escarpment, cuesta, hogback*).
10. Hogbacks are steep ridges exposed as a result of (*faulting, folding, erosion*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Twisted, folded, faulted, and tilted rocks show the effects of __?__.
2. Differences between the old and new position of shore features is called __?__ movement.
3. Force that pulls rocks apart is called __?__.
4. Force that twists rocks is called __?__.
5. The dominant force associated with a shrinking earth would be __?__.
6. The position of rock layers is called __?__.
7. An upward arch in a series of rock layers is a(n) __?__.
8. The volcanic form which results from an explosive eruption is a(n) __?__.
9. Crater Lake, Oregon, is a body of water that collected in the __?__ of an extinct volcano.
10. Eroded plateaus become __?__ mountains.

D. How and Why

1. If you were to find beaches and benches along the California coast 20 ft to 30 ft above sea level, what could you conclude about the former position of the Coast?
2. Why do sedimentary rocks provide the most information about diastrophism?
3. Why are sedimentary layers occasionally found below igneous and metamorphic rocks in parts of mountain chains?
4. If rocks that formerly were deeply buried in a geosyncline are brought to the surface, would you expect them to be folded and faulted, or just faulted? Explain your answer.
5. What forces are dominant in block faulting?
6. Why is volcanic activity often associated with mountain building?
7. Why do volcanoes adopt different shapes at the surface?
8. How might the theory of a heating and expanding earth lead to the idea that continents once were connected and then split apart into their present shapes?
9. What are the major events in the life of a geosyncline?
10. What is the reason that some hills are formed from synclines, and some valleys are called anticlines?

INVESTIGATIONS

1. Recount a Greek myth or a Japanese tale used to explain earth movements. Report on the rising of a volcano such as Krakatoa, Pelee, Mauna Loa, Kilauea, Vesuvius, or Etna.
2. Observe road cuts, river banks, or mountain areas in your region and photograph or draw a picture of an anticline, a syncline, or a fault. Make a sketch map of its location.
3. Send to the U. S. Geological Survey (Washington, D. C. 20242 or Denver, Colorado 80225) for aerial maps of mountain and plateau areas. Locate faulting, folding, volcanic peaks, plateaus, and dissected mountains on the maps.
4. On a world map, indicate major mountain ranges and volcanic areas. Save for a comparison with a map of earthquake areas. (Chapter 18.)

INTERESTING READING

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*Milne, Lorus J., and Milne, Margery, _The Mountains._ Life Nature Library. New York: Time, Inc., 1962.

Volcanoes. United States Department of the Interior, Geological Survey, 1964.

Volcanoes of the United States. United States Department of the Interior, Geological Survey, 1965.

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* Well-illustrated material.

Earthquakes

18

Tremblings of the earth's surface are obvious evidence of diastrophism. Widespread devastation often accompanies the violent shakings of the so-called solid earth. Earthquakes along the Pacific Coast, along the Mediterranean Sea, and in the West Indies are especially frequent and have been noted for centuries. Early Mediterranean civilizations recorded tremblings of the earth, as well as the cracking and buckling that accompanied the quakes. These are minor changes in the earth's surface compared to changes caused by rivers, glaciers, and wind. But, because they are often disastrous, earthquakes are an important area of study.

18:1 *Origin*

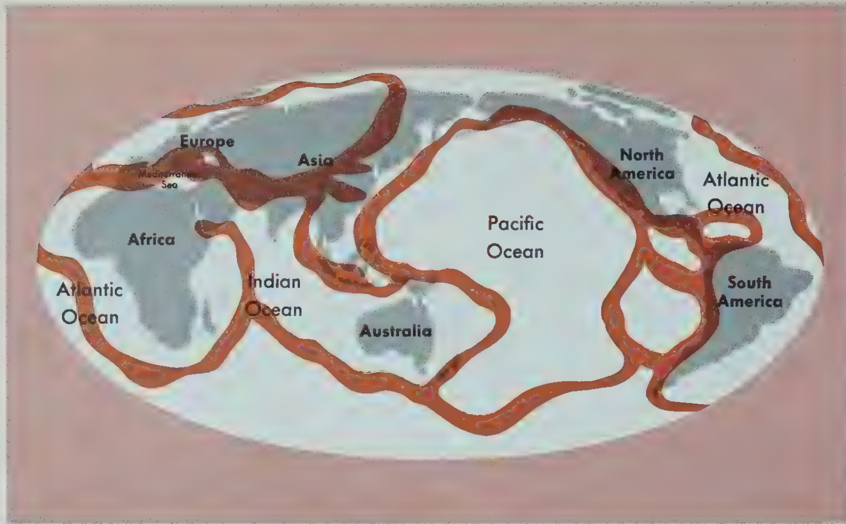
When rocks break because of tension or compression, vibrations start.

Earthquakes are tremblings or shaking of the ground caused by the sudden movement of rocks below the earth's surface. When rocks are pulled apart by tension, or broken by compression, tremors or vibrations spread out in ever-widening patterns. Grasp the ends of a stick in your hands. Now break the stick. Did you feel the vibrations of the breaking process? Drop a pebble in still water. Did you observe an ever-widening circle of waves? Both actions represent, on a small scale, what happens when rocks within the earth are broken.

Vibrations pass from rock particles to rock particles.

Within the earth, rock particles immediately next to a break are set in motion. The motion is passed on to adjacent particles, which in turn pass it on to the next particles. Eventually, the vibration reaches the surface. If the rock break occurs in the upper mantle or deep within the crust, vibrations usually are too weak to cause much damage at the surface. But even weak vibrations can be recorded. If the rock break is near the earth's surface, rocks are set in motion somewhat like water in the

Figure 18-1. Major earthquake regions are most common around the Pacific Ocean border and in a band parallel to latitude including the Mediterranean Sea.



ocean. Unlike water, rocks are brittle and cannot change shape easily to form waves. Instead, rocks buckle, bend, or break when the motion is strong and vibrations are great.

EXPERIMENT. Measure the length of a thick rubber band without stretching it. Now stretch it until the band breaks and measure its length. Does the stretching and breaking of the rubber band change its length? What force breaks the band?

Stand a piece of lath on end and brace it so it cannot move. Try to bend the lath in an arc. What kind of force are you applying to the lath? Now grasp one end of a piece of lath in each hand and break it. Describe the sensation in your hands.

Place two large wooden blocks on a table so they are touching one another. Push one block in one direction and the other block in the opposite direction, so that they slide past one another. This movement in a horizontal direction is like the movement along a strike fault, *such as the San Andreas fault in California. What kind of force are you applying to the blocks? What is the relationship between the rubber band and faulting?*

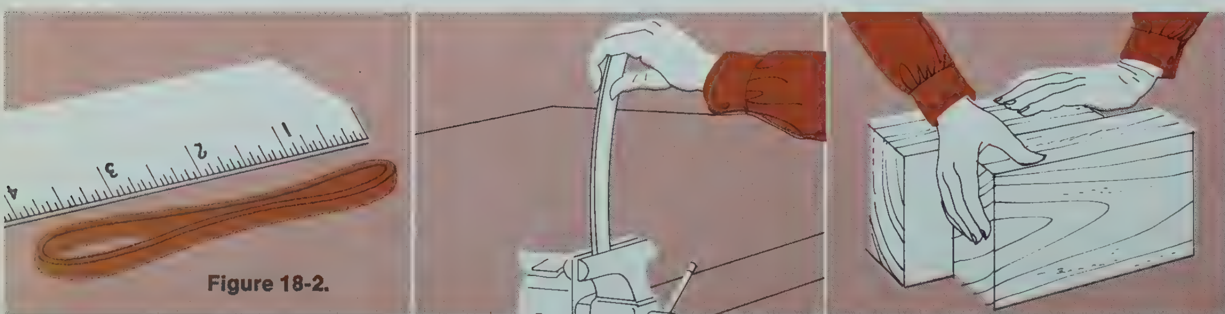


Figure 18-2.

Surface damage following earthquakes occurs in linear patterns, or along lines which can be mapped. Repeated observations of this alignment of quakes led to the idea that the vibrations came from the breaking and movement of rocks along faults. (Section 17:3.)

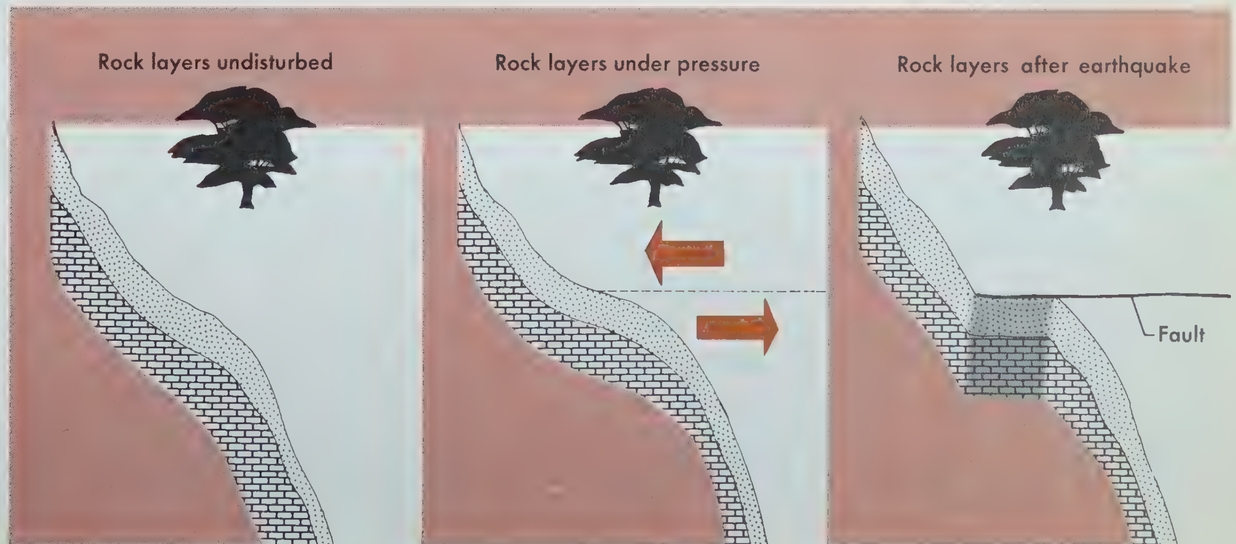
Movement of rocks occurs along faults.

Earthquakes caused by volcanic action and by the collapse of caverns and mine tunnels affect only local areas. These shocks are minor compared to the violent vibrations caused by movement along fault zones or fault planes. For example, horizontal movement occurred during the San Francisco earthquake in 1906. The coastal side of the San Andreas fault moved northward in relation to the landward side. On opposite sides of the fault, movement ranged from 16 ft to 21 ft. Movement extended along the break for about 270 mi.

From studies of the San Francisco earthquake, scientists theorized that slowly accumulating internal forces tended to drag the coastal side of the land northward along the fault zone. Eventually, these forces overcame the strength of the rocks, and they yielded, or broke, suddenly. Prior to the yielding, internal forces had stored elastic energy within the rocks, as energy is stored in a tightly coiled spring. The movement suddenly released the stored energy in the form of earthquake waves and of heat generated by friction between masses of rock sliding along the fault. The forces and energy involved in seismic activity are enormous. You may realize something of their magnitude if you compare the energy required to tear down a large building with the destruction that accompanies an earthquake.

Internal forces cause elastic energy to be stored in rocks.

Figure 18-3. Movement of one rock mass against another causes vibrations known as earthquakes.



When the stored elastic energy exceeded the strength of the rocks, the San Francisco earthquake occurred. The result was like pulling the trigger of a giant gun. Accounting for the triggering processes, however, does not answer the basic question, "What is the source of the energy?"

Heat is probable source for energy resulting in earthquakes.

Heat is the most probable energy source for crustal movements and their accompanying earthquakes. Several theories that may account for crustal movements were described in Section 17:2. Because heat is involved in all of these explanations, it is considered the most probable source of earthquake energy.

18:2 *Seismographs*

Earthquakes that are initiated at great depth may not affect the surface visibly. Earthquakes that reach the surface in uninhabited regions may also escape notice. But with the aid of a seismograph (siez′ma graf), even the faintest earth tremors can be recorded.

Earthquake vibrations are recorded by seismographs.

Modern **seismographs** are devices used to detect, measure, record, and analyze vibrations in the earth's crust. An essential requirement of a seismograph is that some point or line within it shall remain steady or at rest. These steady points are usually some form of pendulum. A heavy mass is suspended on a wire or rod, or by a combination of both, from a fixed frame or support. The supporting frames are securely fastened or anchored to the earth. When seismic vibrations cause ground motion, the large mass of the pendulum tends to remain at rest because of its inertia. (Section 1:3.) However, the earth and the supporting frame move because of the vibrations. Suspension systems are designed to avoid transmitting ground motion to the heavy mass which acts as a fixed reference point. Earth and frame move with the shock waves, but the suspended mass remains at rest.

Seismograph consists of fixed frame and suspended pendulum which hangs at rest because of inertia.

A simple seismograph consists of a mass suspended at the end of a vertical wire. A small sharp point, or *stylus* (stie′lus), projects from the bottom of the mass and barely touches a smoke-coated paper tape. This tape is pulled forward or rotated on a large drum. (Figure 18–4.) Such a device will detect an earthquake and record the relative displacement of the ground. Motion of the ground is transmitted to the supporting frame. Due to its inertia, the mass tends to remain motionless. Because this device is affected most by horizontal ground motion, it is classed as a *horizontal seismograph.*

A *vertical seismograph* requires a different type of suspension. A simple vertical seismograph consists of a heavy mass suspended from an elongated coiled spring. A pencil or stylus projects from the side of the mass and just barely touches the surface of a smoked paper tape. The paper tape is pulled along a vertical plane or rotated on a large drum. (Figure 18–4.)

Modern instruments at a seismic observatory are more elaborate and refined than the simple devices just described, but the principles of operation are the same. Commonly, three seismographs are used together. One records vertical movements, a second records north-south horizontal movements, and a third records east-west horizontal movements.

Sensitive seismographs equipped with electronic amplifiers commonly record *background noise*, or unwanted vibrations. Sources of such noise are ocean waves, surf, trains, and heavy trucks. Scientists try to reduce these unwanted vibrations by carefully selecting observatory sites and carefully constructing observatory piers. Concrete piers support the instruments, but they have no mechanical contact with the observatory buildings. This isolation protects the instruments from unwanted building vibrations.

Seismograms, the lines recorded by a seismograph, indicate earthquake intensity by their wave-like patterns. Wave height, or *amplitude* (am′pli teud), is measured on a scale used by all seismic observatories. The magnitude of an earthquake is indicated by the amount of amplitude. When stations within 60 mi of the center of the earthquake record 7 to 8 units on this scale, a major earthquake is in progress.

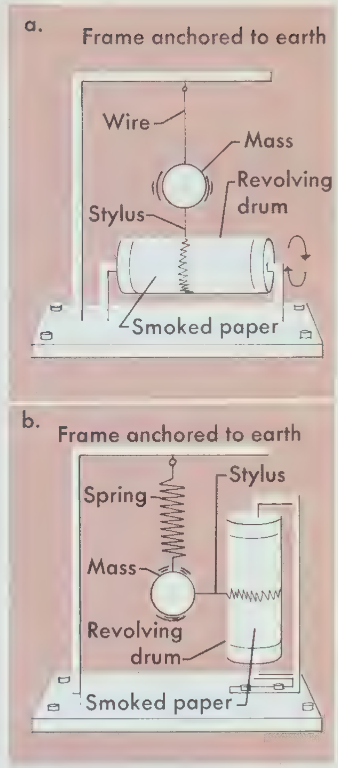
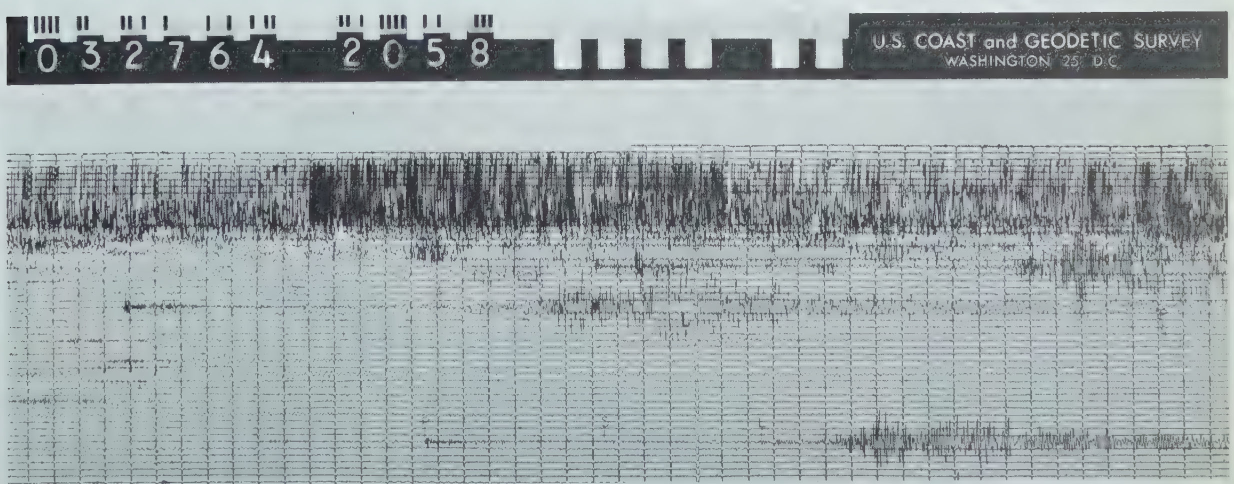


Figure 18-4. (a.) Horizontal movement of the earth causes the mass to move from side to side as the drum revolves. (b.) Vertical movement of the earth causes the mass to move up and down as the drum revolves.

Figure 18-5. During the 1964 Alaskan earthquake, this seismogram recorded vibrations.



ESSA Photo

Seismic observatories are equipped to record two types of vibrations which travel through the earth from the site of the earthquake. Horizontal waves are called *P waves*, or *primary waves*. *P* waves also are known as longitudinal or compressional waves because particles vibrate back and forth lengthwise, or in the direction of wave travel. As movement passes from rock particle to rock particle, regions of compressed rock particles alternate with regions of separated rock particles. A "slinky" toy that is held at one end, then given a slight jerk, illustrates the movement of the *P* wave.

Vertical waves are called *S waves*, or *secondary waves*. *S* waves also are known as transverse or oscillatory waves. Vibrating particles move up and down at right angles, or transversely, to the direction of vibration of the *P* wave. By moving the free end of a rope up and down rapidly, *S* waves can be produced in a rope which is fixed at one end. *P* waves and *S* waves travel within the earth, but never along the surface.

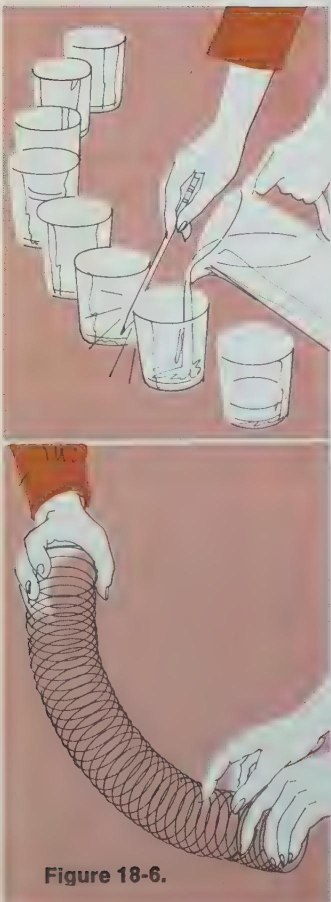


Figure 18-6.

EXPERIMENT. Place eight glasses in a row. Strike each of them gently with a pencil. Arrange them so their sounds reproduce a musical scale. If the glasses do not produce all the notes of the scale, add water to each glass until you duplicate the sounds of the scale. Why does water change the sound? What is the relationship between earthquakes and sound waves? Why do we not hear earthquake vibrations?

Have two students hold a "slinky" toy stretched loosely between them. To send vibrations along the toy, pluck the spring near one end. What happens? Compare this movement with earthquake vibrations. How do builders muffle sounds in large rooms? How do different materials in the interior of the earth affect the vibrations of an earthquake?

By interpreting the recordings of both *P* waves and *S* waves, the location of an earthquake's epicenter (ep i sent′er) can be determined. The *epicenter* is a point on the earth's surface directly above the rock break or fault within the earth. The *focus* of an earthquake is the actual location of the rock break or fault within the earth. The focus of an earthquake may be as deep as 400 mi to 500 mi directly below the epicenter.

P waves travel almost twice as fast as *S* waves. Therefore, the *P* waves always arrive first at the seismograph station. Using time-distance tables and curves recorded and plotted from many earthquakes, a seismologist can determine how far from his station the earthquake originated. The seismologist

first determines from his seismographs how much time has elapsed between arrival of the P waves and S waves. Measurements have been tabulated and adjusted to provide the distance in miles from epicenter to observatory for any time interval between the arrivals of the P and S waves. However, the distance from observatory to epicenter determined in this manner is only an approximation. One reason for inaccuracy is that an epicenter is assumed to be a point. Actually, the epicenters may involve large areas or great lengths. Recall that the San Francisco earthquake was caused by rock movements along a fault length of 270 mi.

Distance between observatory and epicenter is calculated on basis of time elapsed between arrival of P waves and S waves.

If observatories have two horizontal seismographs, one can record P waves from the north-south direction; the other can record waves from the east-west direction. Comparison of the two seismograms is an aid in determining the direction of the epicenter from the observatory.

When three or more observatories exchange records of the same earthquake, the location of the epicenter can be determined with greater accuracy. On a world map, each recording observatory is plotted as a center point. Then, a circular arc is drawn from each of these points. The radius of each arc is the distance from observatory to epicenter as determined from time-distance tables. The point of intersection of three or more arcs is the location of the epicenter. (Figure 18–7.)

Intersection of arcs based on distance from three observatories, when inscribed on a world map, indicates epicenter of an earthquake.

P and S waves travel away from fault zones and spread out in every direction. These waves do not take the shortest path

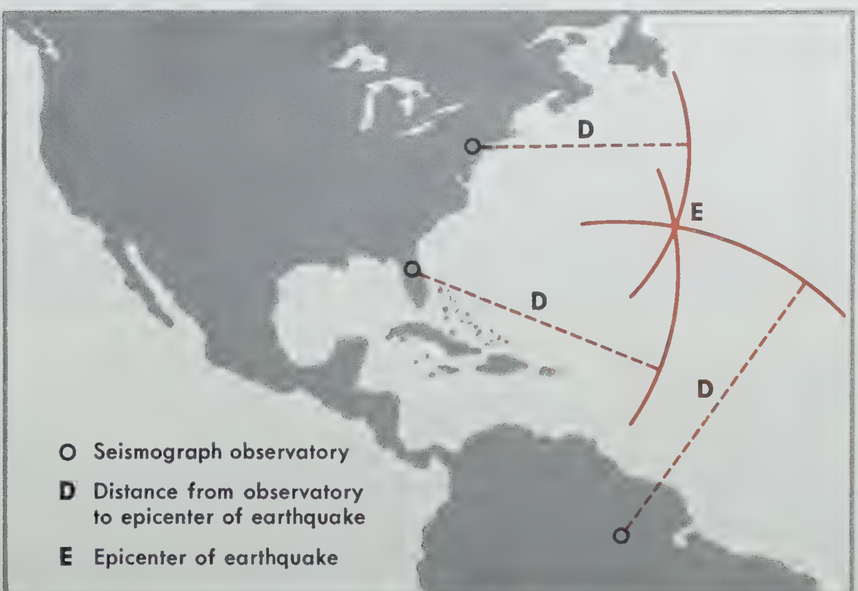
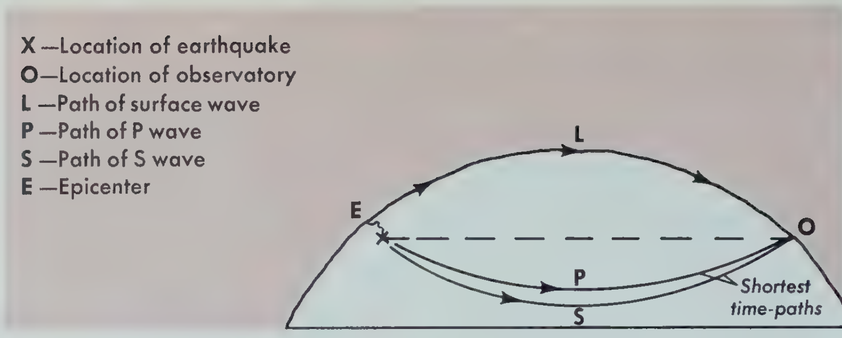


Figure 18-7. Three seismic observatories locate the epicenter of an earthquake by drawing circles, using the observatories as centers and a radius equal to the computed distance from earthquake to observatory.

Figure 18-8. Earthquake waves are separated into the L, S, and P waves which travel at different speeds through the earth.



Shortest time-path of P and S waves depends upon wave velocities of material within the earth.

between fault and seismograph station. Instead, they follow the shortest *time-path.* The shortest time-path depends on the changes in wave velocities within the earth. If wave velocity were uniform throughout the earth, the shortest time-path would be a straight line between fault and seismograph. But velocity is not uniformly distributed; it actually increases with depth. *P* and *S* waves follow somewhat similar, but not identical, paths. Recall that the *P* wave travels almost twice as fast as the *S* wave.

Complex waves, called **surface waves** or **L waves,** follow along the surface of the earth from epicenter to observatory. Arrival time and amplitude of *P*, *S*, and *L* waves of an imaginary earthquake are shown in Figure 18–9. Notice that maximum amplitude, indicated by the letter *M*, occurs during passage of the *L* wave. Amplitude gradually decreases after passage of the maximum until earth movements finally cease.

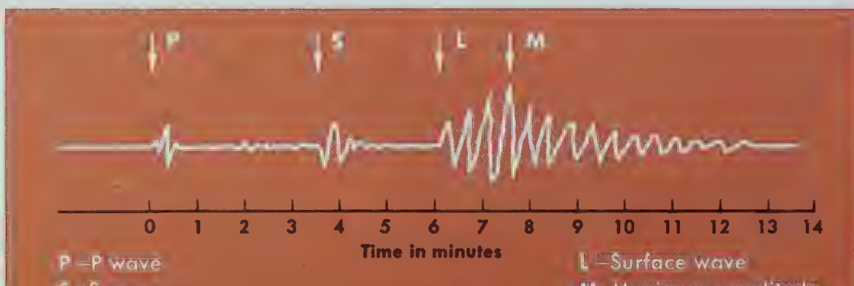


Figure 18-9.

PROBLEMS

Refer to Figure 18–9 to answer these questions.

1. Estimate the elapsed time between the arrival of the *P* wave and the *S* wave.
2. Estimate the elapsed time between the arrival of the *P* wave and the time of the greatest surface damage.

3. Assume that P waves travel twice as fast as S waves. What is the total travel time required for the S wave to travel from the earthquake focus to the seismograph?
4. Assume that S waves travel 2 mi/sec. How far from the seismograph is the earthquake focus? What is the distance from seismograph to earthquake focus in kilometers?
5. Assume that P waves travel twice as fast as S waves. What is the total travel time required for the P wave to travel from the earthquake focus to the seismograph?
6. Assume that the P wave travels 4 mi/sec. How far from the seismograph is the earthquake focus?
7. A velocity of 2 mi/sec is equivalent to how many kilometers per second?
8. Is the velocity of the L waves faster or slower than the velocity of the P waves and the S waves?
9. Estimate the elapsed time between the arrival of the P wave and the L wave.
10. You calculated the travel time of the P wave from focus to seismograph in Problem 5. Use this time and the elapsed time as determined in Problem 9, to estimate the total travel time required by the L wave to travel from focus to seismograph.
11. On a separate sheet of paper, draw a time scale with minute intervals every ½ in. Draw a vertical arrow above zero and label with an X. Zero time (X) indicates the time the earthquake occurred. Recall from Problem 5 the total travel time required for the P wave to travel from earthquake focus to seismograph. Draw a vertical arrow at the correct point on the time scale. Label it P to indicate the correct arrival time of the P wave at the seismograph as compared with the time of the earthquake. Draw and label similar vertical arrows indicating the correct arrival time of S, L, and M. Assume that the earthquake occurred at 3:09 P.M. From the new time scale, prepare a table listing the time of the earthquake occurrence and the arrival time of P, S, L, and M.
12. Assume that the earthquake focus was close to the earth's surface. Also assume that the distance to the epicenter was 840 mi. What is the velocity of the L wave in miles per second? What is the velocity of the L wave in kilometers per second?

18:3 *Effects of Earthquakes*

Earthquake vibrations cause much indirect damage.

Earthquake vibrations may affect large areas and cause tremendous damage to large cities. Indirect damage resulting from a quake often causes almost as much loss as the earthquake itself. Damage to railroads, highways, and utilities may cause interruptions of public services, such as transportation, electricity, communications, water, and sewers. Fires resulting from broken gas mains may rage out of control because broken water mains cannot supply water for fire fighting. Lack of water and shattered sewer systems interfere with sanitation and create health hazards. Food delivery may be interrupted or prevented; food losses may be high due to breaks in power lines which supply electricity to refrigeration systems.

U.S. Dept. of the Interior

Figure 18-10. Earthquake damage at Anchorage, Alaska, caused by surface waves.

During an earthquake, buildings may vibrate and sway so violently that they crumble and collapse. Buildings of stone or brick are especially subject to collapse.

Flexible buildings that permit swaying without breaking or separating are best suited for construction in earthquake areas such as Japan and the Pacific Coast. Reinforced concrete and steel framing in large buildings and wood in small structures withstand most earthquake shocks. Because these materials have flexibility within only a limited range, damage may be expected during severe earthquakes.

Buildings in areas subject to earthquakes should be of flexible materials.

Coastal cities are subject to severe damage by sea waves called *tsunamis*. (Section 12:3.) Tsunamis are caused by earthquakes under the ocean or under the land area near the coast.

Submarine landslides triggered by shaking of the sea floor also may cause tsunamis.

Tsunamis, produced by underwater vibrations, cause extensive damage on shore zones.

Tsunamis may be only a few feet high near their origin. However, a large volume of water is set in motion by wave fronts 100 mi wide and wave heights of 5 ft. Waves 5 ft high are not unusual at sea, and may pass a ship unnoticed. But this huge wave of water moves at a high speed, often 400 mi/hr to 500 mi/hr. When the waves reach shallow water along the coast, the water suddenly piles up. In V-shaped bays, a sudden increase in wave height to 100 ft is likely to occur. Such a wall of water moving at this high speed is so destructive that few man-made shore structures can withstand its force.

Seismologists are unable to predict when and where earthquakes will occur.

Earthquakes commonly are regarded as disastrous events because they may cause enormous loss of life and property destruction. But, during all of geologic time, earthquakes have not changed the earth's surface greatly. Some earthquakes have formed cliffs; some have altered drainage systems; some have caused landslides which dammed lakes. But, compared with the work of rivers and glaciers, earthquakes are relatively ineffective. Why are geologists so interested in earthquakes?

If scientists could predict where and when earthquakes will occur, they could help prevent disaster. They know which areas are most subject to earthquakes, but at present it is impossible to predict when rocks under strain will actually break and cause damaging vibrations. Today's predictions are too generalized and widespread to be of much immediate help. About 80 percent of all earthquakes occur in the vast region of the Pacific Ocean. California, Alaska, Chile, Japan, and mid-ocean areas have experienced earthquakes. But there is yet no way to know which area will have the next earthquake.

U.S. Forest Service

Figure 18-11. A new lake is formed in Montana by a landslide that dammed up the outlet of Madison River during an earthquake.

18:4 *Interior of the Earth*

In addition to locating epicenters and predicting and warning of approaching tsunamis, earthquake study is useful in exploring the earth's interior. By measuring the elastic properties of rocks, such as compressibility and rigidity, scientists can calculate expected velocities of P waves and S waves. Direct measurement of velocities in rocks in the laboratory is not practical, but velocities can be read from time-distance curves. These curves are derived from seismograms of earthquakes and man-made explosions.

Seismograms are used in the study of earth's interior.

Rock density and elasticity determine velocity of seismic waves.

Velocity of sound waves varies with rock density and elasticity. Elasticity is the more important of the two governing factors. Tables are available which list velocities of *P* and *S* waves in most types of rocks. Values are given for wave velocities in rocks at the surface, at various depths, of different geologic ages, and of different densities. Igneous rocks commonly have higher seismic velocities than sedimentary rocks. But some velocities are common to both types of rock. Variations in velocity provide useful information. From seismograms, seismologists can distinguish between different types of rocks traversed by seismic waves between the earthquake focus and a given seismograph station. Data from stations distributed throughout the world have been used to interpret the density of the earth's interior.

Variations in seismic velocities indicate variations in type of rock traversed between focus and station.

In 1909, Andrija Mohorovicic, a Yugoslavian seismologist, recognized a sudden increase in *P* wave velocity about 25 mi below the earth's surface. At this depth, velocities increase from about 4 mi/sec to about 5 mi/sec. Mohorovicic knew that the velocity of *P* waves increased gradually with depth. Velocities increased from 3¾ mi/sec at the surface to about 4 mi/sec at a depth of 25 mi. A velocity of 3¾ mi/sec is normal for granite; 4 mi/sec is normal for basalt.

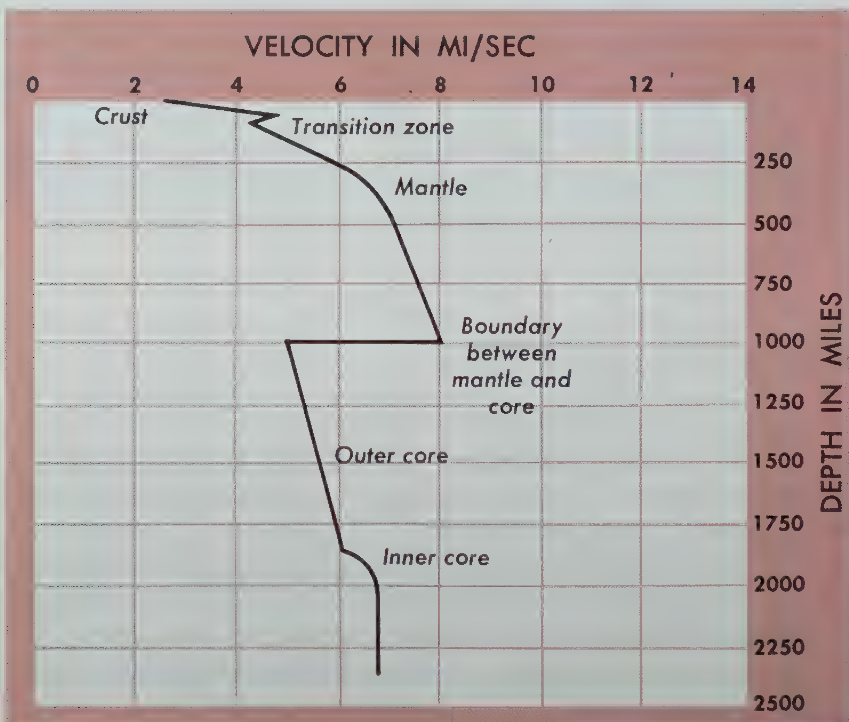


Figure 18-12. Velocity of the P seismic wave varies with depth, indicating changes in both density and the state of matter.

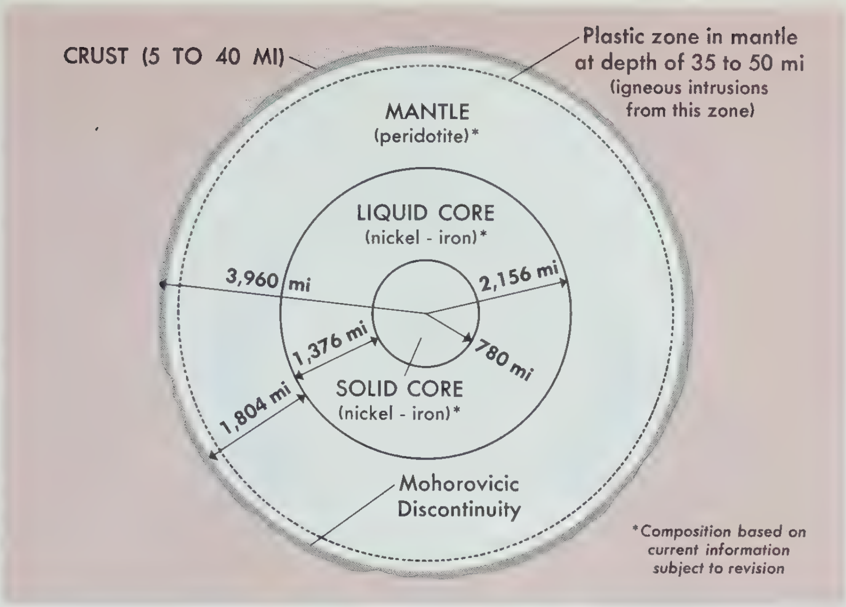


Figure 18-13. The structure and composition of the earth's interior are suggested by earthquake vibrations received at many widely distributed seismograph stations.

The abrupt velocity increase observed by Mohorovicic indicated a sudden change, or discontinuity (dis kahnt en eu′ at ee), in the density of material at this depth. This change is called *Mohorovicic* (moh ha roh′va chich) *discontinuity*, or simply *Moho*.

Sudden increase in seismic velocity 25 mi below the surface, recognized by Mohorovicic, indicates a change, or discontinuity, in rock character.

At a depth of 25 mi, the abrupt change in velocity indicates that basalt is replaced by some other rock material. Several rocks have velocities that fit the observed value of 5 mi/sec. However, scientists do not agree on the composition of the rock at this depth. Some scientists have proposed drilling a deep hole to determine from samples what kind of rock lies below the discontinuity.

The Mohorovicic discontinuity separates the outer layer, called the *crust*, from a lower layer, called the *mantle*. (Section 2:5.) Seismology provides further information about the earth's internal structure and recognition of another layer called the *core*. If the material between the Moho and the center of the earth were solid, an earthquake would send *P* waves and *S* waves directly through the earth's center. Both waves would be recorded by a seismograph located on the side of the earth opposite the earthquake focus. Knowing the location or epicenter of the earthquake, the time at which the quake occurred, and the velocity of seismic waves through crust and mantle, a scientist should be able to predict the travel time for the earthquake wave. However, seismic waves do not arrive at the seismograph stations at the predicted time. Travel time for the waves is longer than the estimated travel time through a solid.

Seismology indicates that earth is composed of different materials in crust, mantle, and core.

Figure 18-14. Earthquake waves encounter different materials and different conditions that affect their velocity. S waves will not pass through the liquid core; P waves indicate a solid inner core.

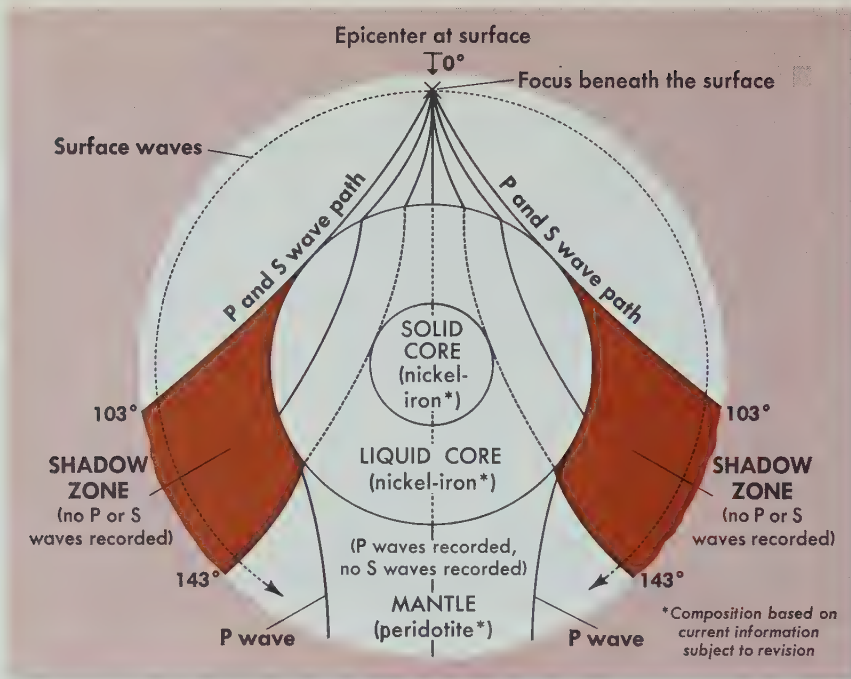
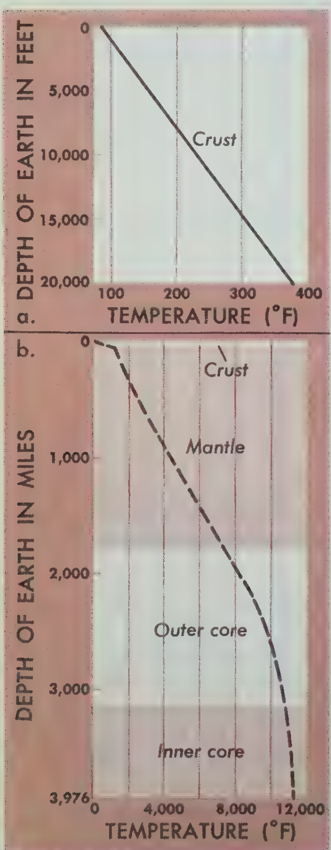


Figure 18-15. (a.) That temperature rises with depth is demonstrated by measurements in wells drilled for oil. (b.) Estimates for temperatures of the mantle and core are based on the known temperature increase and rock melting points.



This time lag is evidence of a velocity change within the earth. It suggests the presence of another kind of material below the mantle. Continual study has shown that different materials exist below the mantle. (Figure 18–13.)

No P or S waves are recorded by seismographs located between angular distances of 103° and 143° on either side of an earthquake focus. (Figure 18–14.) These zones are called *shadow zones*. Absence of *P* and *S* waves suggests the presence of a seismic barrier. The barrier is thought to be similar to a large opaque (oh paek′) ball with a cone-shaped hole cut through it. If the opaque ball is placed in front of a small lamp, light rays pass through the hole, but cast shadows on either side of the opening. Similarly, *P* and *S* waves are screened out in the shadow zone between 103° and 143° angular distance from the focus.

In one respect, the seismic barrier is surprisingly different from the opaque ball. *P* waves come through the cone-shaped opening, but *S* waves do not. In Figure 18–14, seismograph stations located between 143° from the focus receive *P* waves but no *S* waves. Transverse waves, or *S* waves cannot be transmitted through a liquid. From these facts, scientists conclude that the core of the earth is liquid. By outlining boundaries of the shadow zones, scientists calculate that the earth has a liquid core with a radius of 2,156 mi. The average depth from the

earth's surface to the boundary of the liquid core is about 1,800 mi. Still another velocity change suggests the existence of a solid core within the liquid core. The radius of the solid inner core is about 780 mi. Seismic evidence suggests that the earth consists of an outer solid crust, a plastic mantle, a liquid outer core, and a solid inner core. (Figure 18–13.)

Seismic evidence indicates that earth consists of a solid outer crust, the mantle starting with Moho, a liquid outer core, and a solid inner core.

Earth's crust ranges in thickness from 5 mi to 40 mi, with an average thickness of about 20 mi. Compared with the rest of the earth, this outer layer is so thin that it can be represented on a small-scale drawing by the width of a pencil line. The next layer below the crust is known as the mantle. The mantle, which is about 1,800 mi thick, is separated from the crust by the Mohorovicic discontinuity.

Below the mantle is the earth's core, a radius of about 2,156 mi. Its outer boundary is marked by a sharp change in velocity of seismic waves. In the core, *P* waves slow to about one-half their speed through the mantle. Because *S* waves do not travel through the outer 1,376 mi of the core, this part of the core is considered to be liquid. A solid core with a 780-mi radius is probably present within the liquid core.

18:5 *Composition of Earth's Layers*

Seismology is useful in defining the earth's layers and in identifying their materials. But identification is not always positive. Many rock materials have similar values for velocity, rigidity, and density. Enormous pressures and high temperatures within the earth may change the physical properties of the earth's materials and make their identification impossible.

PROBLEM

Examine the seismograph in Figure 18–16. Where do the vibrations of an earthquake cause movement? Which part remains steady during earthquake vibrations? If an earthquake occurred on the side of the earth opposite this seismograph, through what layers of the earth would the vibrations pass? How would the seismogram recorded by this seismograph differ from the seismogram at a station within 100 mi of the epicenter of the quake?

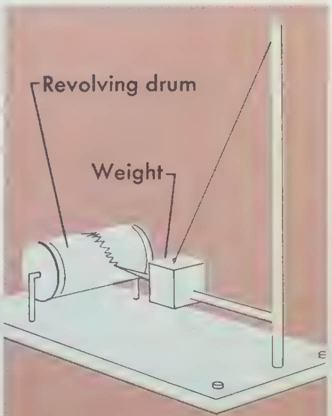


Figure 18-16.

Seismic information, known physical properties of crustal materials, and evidence from meteorites have led to the assumption that the earth's composition changes with depth.

Seismic information suggests an inner core of solid iron or nickel-iron and an outer core of liquid nickel-iron.

Many scientists agree that the inner solid core probably is composed of iron or a nickel-iron alloy. The outer core is thought to consist of iron or nickel-iron, but in the liquid state. Evidence for this composition comes from comparisons with meteorite material and seismic velocities in different kinds of matter.

High-velocity earthquake waves are characteristic of the mantle. Furthermore, high velocities are associated with rocks of high density and rigidity. Peridotite, a magnesium-iron silicate, fits the high velocity requirements of a solid, rigid material. But other mixtures have similar properties. It is hoped that positive identification of mantle material will come from rock samples extracted during drilling into the mantle.

Seismic velocities indicate crustal material of granite overlying basalt on the continents and basalt alone beneath oceans.

Recall that the outermost layer of the earth ranges in thickness from 5 mi to 40 mi and has an average thickness of 20 mi. *P* waves travel in this layer at the rate of $3\frac{3}{4}$ mi/sec, the normal velocity in granite. Velocities increase with depth to a speed of about 4 mi/sec which is normal in basalt. Because these values for velocity in granite and basalt are so close to the observed *P*-wave velocity in the upper 20 mi of the earth, it is thought that granite may overlie basalt in the crust. However, granite is absent in ocean basins where the crust is only 3 mi to 5 mi thick. Only velocities characteristic of basalt are present in the crustal layer of the ocean.

Problems

1. Refer to Figure 18–13 and convert all of the dimensions for the layers of the earth from miles to kilometers.
2. Draw a cross section of the earth similar to Figure 18–13, but change the scale to 1 in. = 3,187.8 km. Use the conversions from Problem 1 and indicate all of the dimensions in kilometers. If your measuring device is not divided into $\frac{1}{10}$-in. segments, convert the fractions $\frac{1}{8}$ through $\frac{7}{8}$ to decimals. Then estimate the radius measurements. You may wish to use a slide rule. Radius of earth in inches on the cross section may be found by simple proportion.

MAIN IDEAS

1. Internal forces of tension or compression cause rocks to break along fault lines and start vibrations which pass from rock particle to rock particle.

2. Elastic energy, probably produced by heat, is stored until rocks reach their limit of strength. Earthquakes release stored elastic energy.
3. Both horizontal and vertical seismographs consist of a fixed frame and a suspended pendulum which remains at rest because of inertia. The frame supports a tape on which vibrations are recorded by a stylus which is attached to the pendulum.
4. *P* or primary waves vibrate in the direction of wave movement. *S* or secondary waves vibrate at right angles to the direction of *P* waves. *P* and *S* waves spread out from the focus of the rock break. The epicenter is directly above the focus of the rock break.
5. Distance from seismic observatory to earthquake is determined by measuring the time elapsed between arrival of *P* waves and *S* waves. *P* waves travel almost twice as fast as *S* waves. Intersection of three circular arcs drawn on a world map locates the epicenter. The radius of each arc represents epicentral distance from an observatory.
6. *P* and *S* waves reach observatory by shortest time-path governed by material through which they pass. *L* waves travel through surface material and cause maximum amplitude of seismogram.
7. Earthquakes and tsunami from undersea disturbances are less effective in changing earth's surface than either rivers or glaciers.
8. Scientists study seismograms to detect variations in rock material. These variations are indicated by different seismic velocities.
9. Studies of seismic velocities indicate that a sudden change, called Mohorovicic discontinuity (Moho), occurs in earth's matter 25 mi below the surface. The Moho marks the boundary between basalt of the crust and an undetermined material of the mantle.
10. Seismic waves are screened out by shadow zones between 103° and 143° angular distance from an earthquake focus. *P* waves penetrate to the far side of earth.
11. Seismologists conclude from studies of seismic velocities that the earth is composed of four layers. They picture an outer solid crust about 20 mi thick, a plastic mantle about

1,800 mi thick, a liquid outer core 1,376 mi thick, and a solid inner core with a radius of about 780 mi.

12. Earth may consist of an inner core (iron or nickel-iron), a liquid outer core (nickel-iron), a plastic mantle (peridotite), and a solid crust (basalt under the sea with granite above basalt on the continents).

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

amplitude	horizontal seismograph	seismic
background noise	Moho	shadow zone
discontinuity	opaque	time-path
epicenter	primary waves	vertical seismograph
focus	secondary waves	vibration

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Earthquakes are more common in some parts of the earth than in others.
2. Seismographs at one location permit accurate determination of the epicenter of an earthquake.
3. P waves travel faster than S waves.
4. Moho is a city that has experienced frequent, severe earthquake damage.
5. A suspended mass that tends to remain at rest during an earthquake is an essential part of a seismograph.
6. P waves and S waves are not recorded by seismographs located in shadow zones.
7. Average thickness of earth's crust is about 1,800 mi.
8. Sudden velocity changes of earthquake waves are evidence of a change in earth composition.
9. Large buildings with steel frames are usually more resistant to earthquake damage than buildings of similar size composed of brick or stone.
10. Earthquakes are evidence of diastrophism.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. The seismic wave with greatest velocity is the (*P*, *S*, *L*) wave.
2. Earth's mantle is thought to be composed of (*granite*, *peridotite*, *basalt*).
3. Earth's core is composed of (*silicates*, *iron-nickel*, *iron-lead*).
4. Average horizontal movement along the San Andreas fault during the San Francisco earthquake was approximately (*18*, *78*, *108*) ft.
5. Focus is the location of a(n) (*rock-break*, *observatory*, *shadow zone*).
6. The *L* wave travels through material in the earth's (*core*, *surface*, *mantle*).
7. Maximum damage to cities comes from the (*P*, *S*, *L*) wave.
8. Greatest change in the earth's surface is caused by (*earthquakes*, *rivers*, *wind*).
9. The Mohorovicic discontinuity separates the crust from the (*solid core*, *liquid core*, *mantle*).
10. As depth increases, seismic wave velocity (*increases*, *remains the same*, *decreases*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Most probable energy source for crustal movements or earthquakes is __?__.
2. The compressibility, rigidity, and density determine seismic wave __?__.
3. Earthquakes occur when stored __?__ energy exceeds the strength of rocks.
4. The larger the __?__ on a seismogram, the greater is the energy.
5. Epicenters are located directly above the __?__.
6. Earthquakes under the ocean or near the coast and submarine landslides may be the cause of seismic sea waves called __?__.

7. The boundary between the crust and mantle is called the ___?___.
8. Knowledge of the structure and composition of the earth's interior has been gained from ___?___.
9. *S* waves never travel along the earth's ___?___.
10. Earth's composition is assumed to change with ___?___.

D. How and Why

1. Why is epicentral distance, determined from time-distance tables from a single seismogram, only an approximation?
2. Explain why *P* waves and *S* waves do not follow the shortest path from earthquake focus to seismograph station.
3. Although 80 percent of all the earthquake energy is released in or along the Pacific Ocean, why is it difficult to predict the time and the location of the next earthquake?
4. If changes of seismic velocity can indicate changes in the type of rock in the crust as compared to the mantle, why is there interest in drilling into the mantle and sampling its rock?
5. Why may the arrival of the *P* wave on a seismogram be more positively identified than the arrival of the *S* wave or *L* wave?
6. If seismic sea waves, or tsunamis, can reach heights of 50 ft to 100 ft in bays and harbors, how can they pass ships at sea without being observed and reported?
7. Why are two horizontal seismographs usually installed in a well-equipped seismic observatory?
8. What is the nature of the stored energy in rocks that causes them to break?
9. How is diastrophism related to earthquakes?
10. What is the probable source of the stored elastic energy that causes quakes? How is the energy transferred and stored in the rocks?

INVESTIGATIONS

1. From library research, report on one of the following earthquakes: Lisbon, Portugal, 1755; San Francisco, 1906; Tokyo, 1923; Yellowstone Park, 1959; Alaska, 1964.

2. On a world map, show the areas of major earthquake activity. Compare this with your map of volcanic activity. (Chapter 17.)
3. List some recommendations for building specifications in areas subject to earthquakes. Investigate requirements in California compared to building requirements of neighboring states. Research the earthquake-proof hotel designed by Frank Lloyd Wright after Japan's 1923 earthquake. Did it withstand later earthquakes?
4. Locate a seismograph station and request some recordings to discuss with the class. Your local weather bureau might direct you to the nearest station.

INTERESTING READING

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Earth History

The crust of the earth with its imbedded remains must not be looked at as a well-filled museum, but as a poor collection made at hazard and at rare intervals.

Charles Darwin (1809-1882)

Although Charles Darwin was primarily a naturalist, his patient observation of organic forms laid the foundation for a systematic study of geologic history. The fact that fossils were the remains of plants and animals preserved by burial had been recognized by a few scientists as early as the fifteenth century. Classification of fossils was begun in the seventeenth century, but no correlation was made between the age of the fossils and the rock layers in which they appeared.

William Smith, a British surveyor, discovered that rock layers could be recognized by the fossils they contained and could be dated in relation to other rock layers. Other earth scientists found evidence of geologic revolutions in the sudden and distinct changes in types of fossils.

As a reasonably accurate dating of rocks became possible with the use of radioactive elements, earth scientists began a system of age determination of rocks. A geologic column by which rocks and fossils are correlated gives a fairly accurate picture of the long, long history of the earth.

UNIT Five

Dating Geologic Time

Knowledge of things and their properties, which Severinus advised his students to gain, depends on knowing their history. Two important questions about the history of the earth are: "How old is the earth?" and "How can you tell how old it is?"

19:1 *Units of Time*

Earth's age is determined by studying changes in rocks and former living organisms.

The age of the earth has been estimated from rates of change in earth materials. Some changes in earth materials require millions, or even billions, of years. Accurate methods for determining age based on such long-term processes are difficult to develop. Two branches of geology, **stratigraphy** (stra tig′ra fee) and **paleontology** (pae lee ahn tahl′a jee), work together to pry secrets of age from rocks of the earth's crust. *Stratigraphers* (stra tig′ra fers) study the composition and arrangement of layered, or stratified, rocks. *Paleontologists* (pae lee ahn tahl′a jists) study the remains of plants and animals which have been preserved in the earth's crust by natural processes. Remains of past life, called *fossils*, are found commonly in sedimentary rocks.

Scales for measuring age depend upon a regularly repeated action.

All measurements require an accurate scale. Common units of time measurement are based on an action which is repeated at equal intervals. Earth's time units are based on the regularly repeated motions of rotations and revolution. (Section 1:4.) Earth's rotation on its axis gives rise to the unit called one day. Months are units related to moon's revolution around earth. Years are units based on earth's revolution around the sun. Geologists cannot always determine the age of various earth periods in terms of years. Many divisions of geologic time are based on estimates and relationships among events.

Measured in earth years, the planet earth has had a long life. Scientists estimate that the earth is approximately 4.5 billion years óld. Man's history on earth spans, at the most, less than one million years. Compared with some members of the universe outside our solar system, the earth may be extremely young. But compared with man's recorded history, 4.5 billion years is a long time.

The earth is approximately 4.5 billion years old.

19:2 *Estimates of Earth's Age*

One of the first attempts to measure the age of the earth was based on the **molten earth theory**. If the earth was molten when it was first formed, and if it has been cooling at a measurable rate, the yearly rate of heat loss at the surface should be a measure of the age of the planet. Based on this theory, the earth has been estimated to be about 20 million years old. But there is some evidence that the earth never was molten. Furthermore, heat has been added to the earth by the decay of radioactive elements in the interior. Because the amounts of added heat are not known, and because the earth may have had a cold beginning, the molten earth theory cannot be accepted as an accurate estimate of the earth's age.

Heat loss from the crust is an unsatisfactory measure of earth's age because undetermined amounts of heat are being added constantly.

Another suggested method for establishing the earth's age is the **salt method.** This measurement is based on the amount of salt ($NaCl$) in seawater. Each year salt is carried to the ocean by rivers. If the amount of salt accumulated in the ocean by the evaporation of seawater is divided by the amount of salt contributed by rivers each year, the answer should be the correct age of the earth. However, this method has many weaknesses. If the estimated age is to be correct, it must be assumed that the oceans originally contained only fresh water. Furthermore, thousands of cubic feet of salt now are buried on land where the seas once covered the continents. Scientists cannot be sure that all such land deposits have been discovered. Thus, the accuracy of such calculations is uncertain. Another problem is the fact that rivers are eroding the continents faster today than they did during much of past geologic time. Salt is probably being added to the ocean more rapidly now than in the past.

Weaknesses in the salt method include possible variation in the erosion rate, impossibility of measuring all salt deposits trapped on land, and the possibility that oceans and earth may not be the same age.

The **sedimentation method** is another means used to measure the earth's age. The sedimentation method uses the total thickness of all known rock layers as a measure of age. The amounts of sand, silt, and mud carried to the sea are measured yearly. From these measurements, the time required for the

deposition of one foot of sediment can be computed. The rate at which limestone is deposited in reefs and along shores also is determined. The amounts of evaporites formed in evaporite basins are measured. By comparing the rates of deposition with the thickness of sedimentary rock layers, scientists can estimate the time required for such accumulations. But, like the salt method, the sedimentation method is inaccurate, because rivers now carry sediments to the sea at a more rapid rate than in the past. Differences in climate, topography, and sea level occur from time to time. These factors influence the rate of sedimentation. Therefore, an accurate estimate cannot be made unless all of geologic history is known. But the greatest obstacle to a correct estimate of the earth's age by the sedimentation method is the removal of many layers of rock by erosion. The remaining strata do not indicate how long deposition continued, or how rapidly sediments were accumulated.

Errors in sedimentation method arise because rate of river erosion is not constant, layers of sedimentary rock may be missing, and rate of accumulation is not known.

19:3 *Radioactive Clocks*

The most accurate method for estimating the earth's age has been provided through the study of radioactivity. In 1896 Henri Becquerel, a French scientist, discovered the radioactive properties of the element uranium. In 1903, he shared the Nobel prize with the French chemists Pierre and Marie Curie for their work on radioactive elements. The Curies had discovered that certain elements undergo radioactive decay and form other elements. The decay is spontaneous (spahn tae′nee us), occurring without the application of heat or pressure, and it is not part of a chemical reaction. However, like a chemical reaction, radioactive decay always produces or absorbs energy. *Radioactive elements* change into other elements by giving off streams of alpha rays, beta rays, and gamma rays, or by capturing electrons. The loss of protons, or the addition of protons, in the nucleus of the atom causes the change from one element to another. (Section 3:2.) Only a few elements are radioactive, but the few that are found in measurable amounts in crustal rocks are used to measure the age of rocks.

After the discovery of radioactivity, the rate of decay was determined for each radioactive element. Not all atoms of an element decay at the same time. But the same number of atoms decay within a given period of time. Thus, an average rate of decay can be determined. The time period in which one-half of

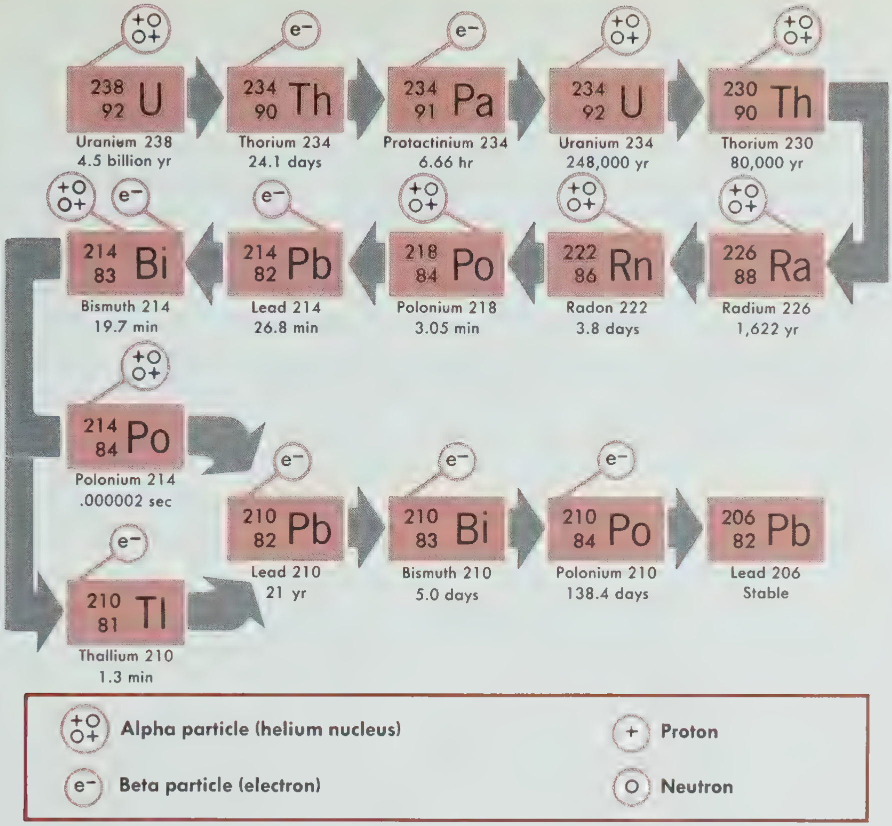


Figure 19-1. Through a series of steps, uranium 238 decays to its stable daughter product, lead 206.

the original number of atoms decays is called the **half-life** of an element. For uranium 238, the half-life is 4.5 billion years. For carbon 14, the half-life is 5,770 years. During radioactive decay, the original, or parent, element forms new products called *daughter elements*. For carbon 14, the daughter product is nitrogen 14. Some daughter products may be radioactive and form other decay products. But eventually, radioactivity is exhausted, and a final *stable*, or inactive, *element* results. Uranium 238 has many daughter elements, but lead 206 is its final stable product.

Half-life of uranium, thorium, potassium 40, and carbon 14 provide absolute dates.

Radioactive elements decay at a measurable rate (half-life) to form daughter elements.

Radioactive decay provides a means of measuring geologic time because the average rate of decay for an element can be determined. Because decay is repeated, a measurement in years is possible. To determine rock ages, the rocks must contain radioactive elements in measurable amounts. Some of the unchanged parent element and some of the stable daughter element must be present. Although such rocks are not common, enough have been found for an age estimate. Rocks which contain uranium, thorium (thohr′ee um), potassium 40, and carbon 14 provide most of the usable time measurements.

Dates obtained from radioactive elements are known as *absolute dates* because they can be measured in years, without reference to any other event. Like birthdates, absolute dates refer to numbers of years before the present. But not all geologic time can be measured in years. Many events can be determined only with reference to other events. For example, you may know that a friend has an older brother and a younger sister. Even though you do not know any of their birthdates, you know the relative ages of your friend and his brother and sister. Many geologic events are expressed in *relative ages* rather than as absolute dates.

Relative dates indicate the order in which events happened.

19:4 *Dates from Rocks*

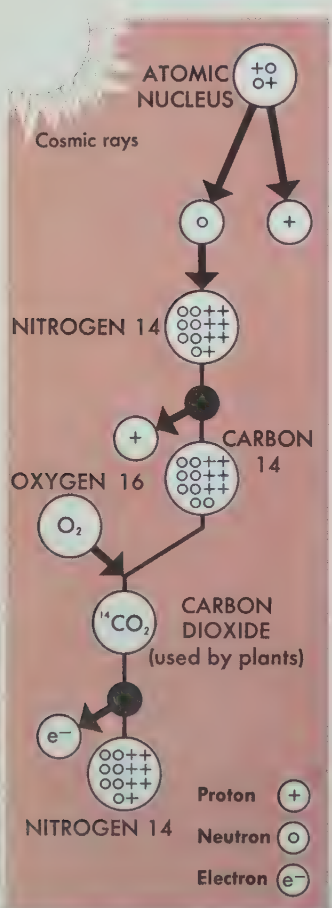
Compared with the vast length of geologic time, absolute dates have been established for relatively few rocks. But more dates are being determined, and eventually geologists will have a much more precise calendar of events.

Measurable amounts of uranium, thorium, or potassium 40 in a mineral may be used to date that mineral. Radioactive dates indicate the time when the mineral crystallized from a magma or precipitated from a solution. Rock ages are interpreted from the age of the minerals contained in the rock. Igneous rocks are most likely to contain uranium and thorium, and the most precise uranium dates come from granites. Potassium 40 occurs in all classes of rocks, and it is providing an increasing number of absolute dates.

The oldest known absolute dates belong to rocks found in Africa. Based on uranium dating, these rocks have been determined to be over 3 billion years old. In North America, the oldest rocks are found in the Canadian Shield (Section 15:3), where dates of 2.7 billion years have been determined. The date of 4.5 billion years for the planet earth has come from analysis of meteorites, not from crustal rocks. Meteorites are matter from space which falls to the earth's surface. Because the sun and its planets are thought to have formed at the same time, the age of meteorites may indicate the age of the earth.

Carbon 14 is a radioactive element which is present in extremely small amounts in all living matter. Carbon 14 is formed by cosmic rays which stream from the sun. When these rays produce neutrons, the neutrons in turn knock a proton from the nitrogen 14 nucleus. When nitrogen 14 loses a proton from its nucleus, it becomes the element carbon 14. In turn,

Figure 19-2. Nitrogen 14 is converted to radioactive carbon 14 by neutron bombardment; carbon 14 reverts to nitrogen 14 through loss of beta rays.



carbon 14 loses a beta particle from its nucleus and reverts to nitrogen 14. This process is continuous. Even though carbon 14 decays to nitrogen 14, the amount of carbon 14 in the atmosphere remains constant because it is always being renewed.

Most of the carbon in the air is present as carbon dioxide (CO_2). Carbon 12 makes up the largest proportion of the carbon (one carbon 14 atom is present for about 1 trillion carbon 12 atoms). Nevertheless, carbon 14 is distributed in approximately equal amounts everywhere on earth. Plants use carbon dioxide in their life processes, and the plants in turn are eaten by animals. Thus, carbon 14 is distributed to all living organisms, and the amount remains approximately constant during their life. After death, carbon 14 is no longer renewed. Consequently, by comparing the amount of carbon 14 remaining in a fossil with the amount present in living things, the date of the fossilized organism's death can be determined.

Carbon 14 has a half-life of 5,770 years. This means that in 5,770 years, half of the original amount of carbon 14 will have decayed to nitrogen 14. In another 5,770 years, half of the remaining carbon 14 atoms will have decayed to nitrogen 14, leaving only one-fourth of the original amount. In this way, organic matter such as charcoal, bones, and wood can be dated. However, organic matter that is older than 50,000 years contains

Carbon 14 indicates age of once-living matter. Half-life of carbon 14 is 5,770 years.

Nitrogen 14 becomes carbon 14 when bombarded by neutrons produced by cosmic rays.

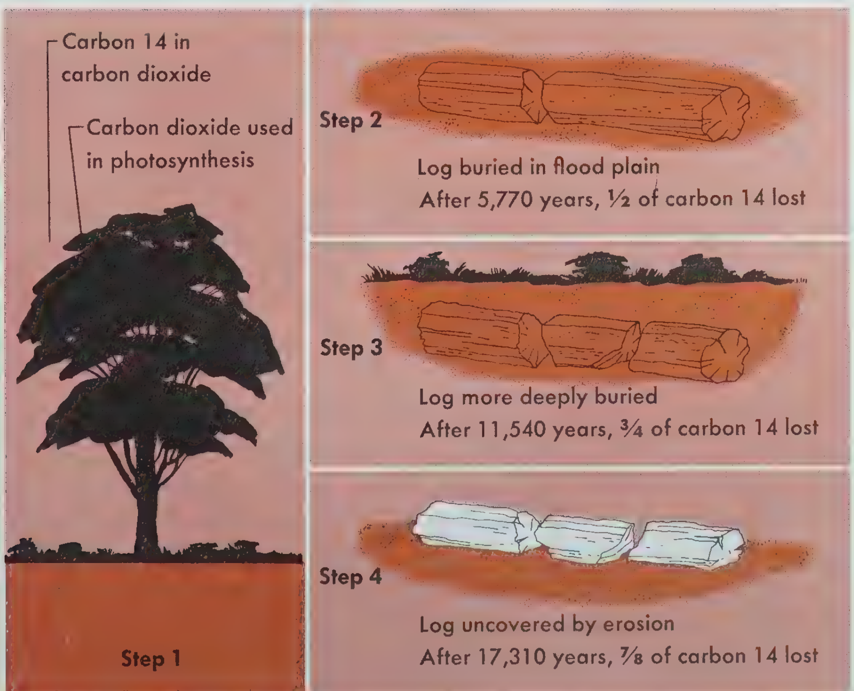
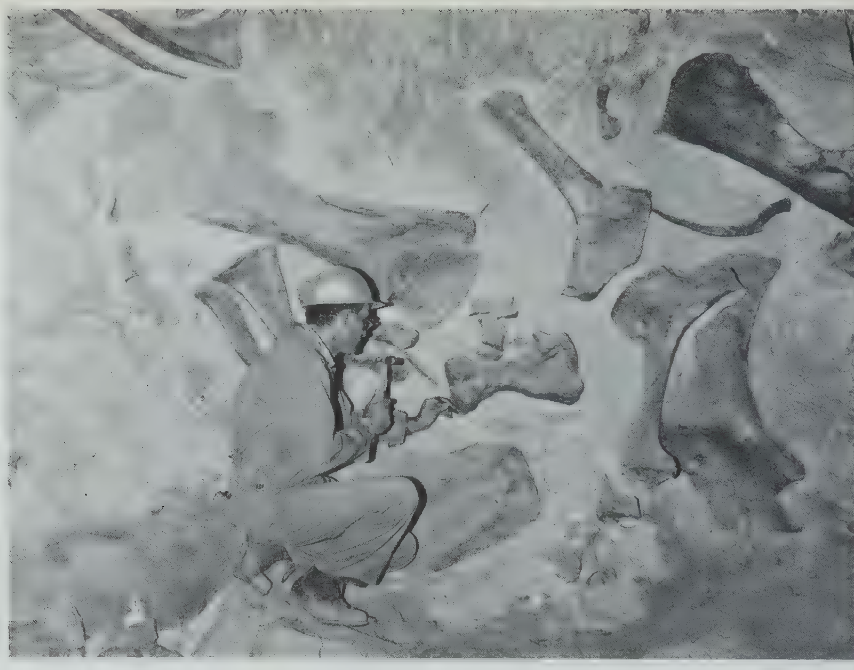


Figure 19-3. Carbon 14 enters plants through photosynthesis; animals eat plants and distribute carbon 14 to the animal kingdom. After death, carbon 14 reverts to nitrogen 14 and is not renewed.

Figure 19-4. Recovery of fossil bones from solid rock involves the tedious and delicate process of chipping.



National Park Service

Carbon 14 is produced in the upper atmosphere at a constant rate and enters all living matter as a result of plant activity. Carbon 14 decays to nitrogen 14, but the amount of carbon 14 is constantly renewed until an organism dies.

too little carbon 14 to be measured accurately. Organic matter less than 1,000 years old cannot be measured accurately because it has lost too little carbon 14. Thus, carbon 14 can be used to date accurately only fossilized living things that died between 1,000 years and 50,000 years ago.

PROBLEM

Draw a circle to represent the amount of carbon 14 present in all living things. Divide the circle into units showing how much of the original carbon 14 will remain in a fossil 11,400 years old, in one 17,100 years old, in one 22,800 years old, and in one 34,200 years old. (Use 5,700 years as the approximate half-life of carbon 14.) How much carbon 14 would be left in approximately 50,000 years? If $1/16$ of the original carbon 14 remains, how old is the fossil? Why is 50,000 years the limit of age determination by the carbon 14 method?

Rocks containing organic matter often can be interpreted as being of the same age as the organic matter they contain. However, fossils of animals that died in caves or fell into ravines must be younger than the rock in which they are found. Such fossils provide relative dates rather than absolute dates for the enclosing rock. Under other circumstances, bones may provide absolute dates for enclosing rocks. For example, if an animal dies and is carried downstream and deposited on a flood plain or delta, its bones and the enclosing rock will be the same age.

Because absolute dating is a complicated process, it may be years before correct dates are established for all units of geologic time. Most geologic dates still are relative, rather than absolute. Recall that dates are called relative if the order of events can be determined, but not the length of time involved. **Relative dates** refer to the relationship between time of deposition and certain events in the geologic sequence.

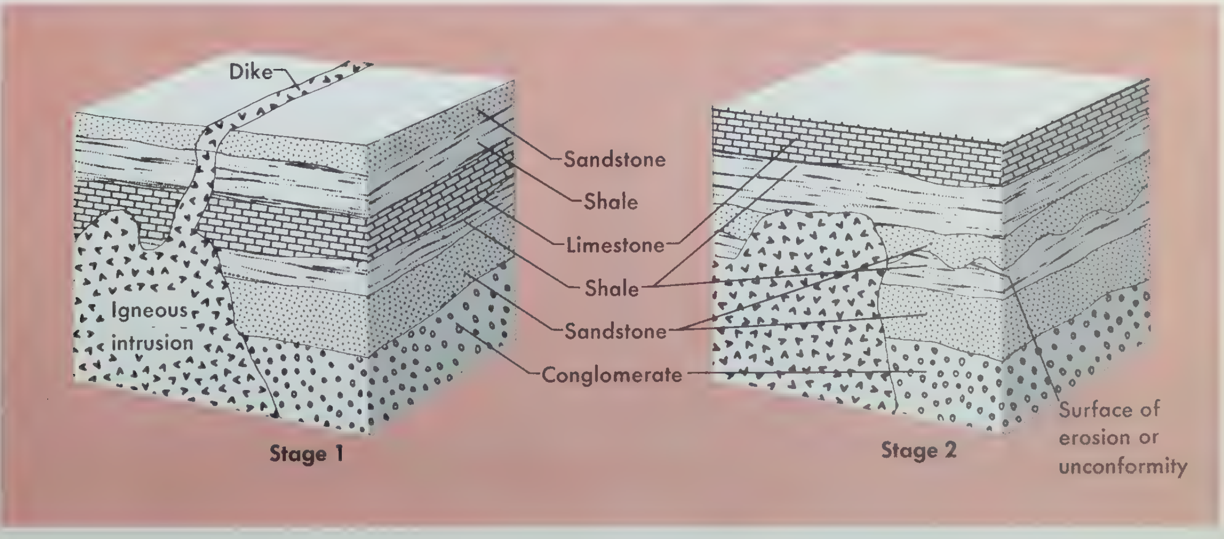
Organisms dated by carbon 14 commonly indicate relative dates for enclosing rocks.

Geologic events that are most easily recognized include faulting, folding, intrusions, and volcanic eruptions. Recall that changes in rock position can be recognized because sedimentary rocks are deposited in a horizontal position near sea level. Furthermore, sedimentary rocks are deposited in succession, with the oldest layer on the bottom of the series and the youngest on the top. This principle of age determination by position of the rock layers in a vertical sequence is called the **law of superposition.** Ages of associated igneous rocks are determined by the **law of crosscutting relationships.** If igneous rocks, such as dikes, cut across sedimentary beds, the sedimentary rock layers must have been there when the dike intruded the sedimentary layers. If sedimentary layers are pushed up by laccoliths or sills which have been squeezed between the layers, then the igneous intrusions are younger than the sedimentary beds. If sedimentary beds are deposited above igneous rocks, the igneous rock must be older. Often the sedimentary bed overlying an igneous mass contains gravel, or even boulders, of the eroded igneous rock. These sedimentary gravels indicate their source in the older igneous rock. Volcanic ash and lava flows are especially useful for establishing a time sequence. The ash of the lava

Mountain building events are useful in determining divisions of geologic time.

The **principle of superposition** states that the youngest rock layers are deposited above older rock layers.

Figure 19-5. In Stage 1, sediments were deposited on the continental shelf, buried, and intruded by magma. In Stage 2, erosion has removed the upper layers, and a new series of beds has been deposited following a second transgression of the sea.



may contain radioactive elements which furnish absolute dates. Then relative dates can be established for the layers above and below the volcanic material.

Both the law of superposition and the law of crosscutting relationships help to establish relative dates for rock layers for which no absolute dates are available. Other evidence that is useful in relative dating includes the presence of folding and faulting. Metamorphism indicates uplift from geosynclinal regions. The uplift of mountains provides a break in the continuity of rock layers. This break is useful for dating geologic events, because the change from folded, metamorphosed rocks to overlying, horizontal sedimentary beds can be readily recognized. Often such major changes in the rock record are used to separate the geologic time scale into units.

PROBLEM

Use Figure 19–6 to correlate the rock layers in *B* and *C* with the layers in *A*. Which column represents the youngest rock formations? Is *C* an older or younger sequence than *A*? What layers are missing from *B* and *C* that are present in *A*? After you have studied Section 19:6, explain how the geologic column of the world has been assembled. Base your reasoning on the correlation of *A*, *B*, and *C*.

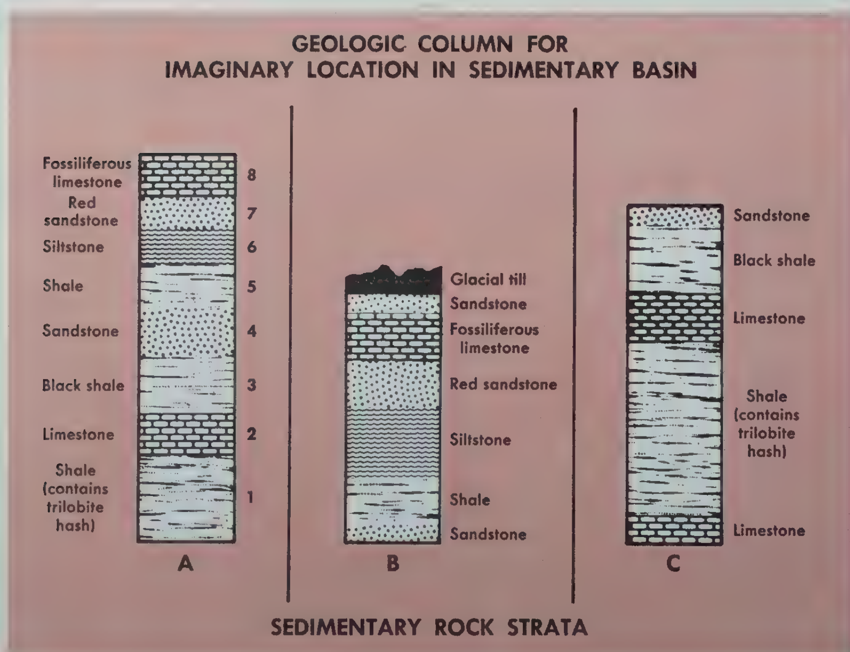


Figure 19-6. Columns A, B, and C indicate the thickness and kinds of rock found at three different locations in the same sedimentary basin.

American Museum of Natural History

Figure 19-7. Some fossils have been preserved by minerals deposited into their pore spaces; others press a record of their shapes into soft rock before they are dissolved.

19:5 Dates from Fossils

Paleontologists study a variety of remains of past life. Occasionally, *entire animals* are preserved. For example, wooly mammoths have been buried and frozen into the ice sheet that has covered Siberia for thousands of years. Leaves or soft-bodied animals may leave imprints if they are buried quickly beneath soft mud. As the plant or animal matter decays, everything disappears except the element carbon. A *carbon impression* reproduces all the fine lines of the leaf or the animal. In fact, in some carbon imprints of worms even their fine whiskers can be recognized. Another type of fossil record is the *footprint*, the track left in soft mud by an animal foot. An animal track is like the footprint which you might leave in snow or wet cement. Snow tracks disappear during melting. But tracks in cement, like tracks in soft mud, are preserved when the material solidifies.

Norfolk & Western Railway

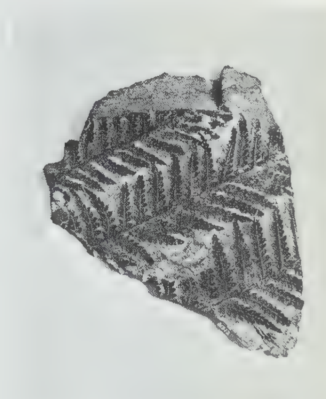


Figure 19-8. An imprint of a fossil fern.

Teeth, *bones* and *shells* of animals may be preserved by quick burial in materials which moisture cannot penetrate. Organic matter decays if it is not buried quickly. Decay is especially rapid in warm, humid climates. Sometimes mineral matter seeps into openings in bones or shells, and replaces the original material. For example, petrified wood is formed when tree cellulose is replaced by silica. (Section 14:4.) *Permineralization* is the process in which the original shell mineral or bone mineral is replaced by another mineral. Other fossil records are the mold and cast. A *mold* is a cavity formerly occupied by an organism. Molds are formed where ground water dissolves an object, and the surrounding material retains an impression of the object. Sometimes the mold is later filled with mud, and the mud filling retains the imprint of the original object. The filling is known as a *cast*.

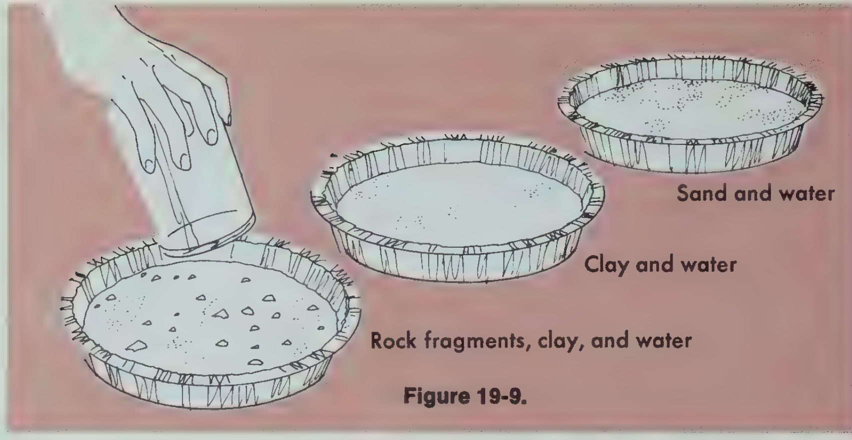


Figure 19-9.

EXPERIMENT. *In three small aluminum pie pans, make three very firm mixtures of sand and water, clay and water, and rock fragments mixed with clay and water. Allow the mixtures to stand for a few minutes. Then press a hard object such as a small block of wood or a glass into the mixtures with enough force to make an impression. Remove the object and compare the impressions made in the mud, in the sand, and in the gravel. In what kind of rock would you expect to find the best fossil impressions?*

EXPERIMENT. *Shape a firm brick from a mixture of clay and a small amount of water, or from plasticene clay. Press a piece of bone or a shell firmly into the brick until most of the object is surrounded. Carefully remove the object so that you have a sharp impression in the brick. What is this hollow that shows the design of the fossil? Now mix patching plaster with water to a thick consistency and use this mixture to fill the impression in the brick. Allow the plaster to dry, and then break away the clay brick. What is the plaster object that duplicates the original bone or shell? Many similar casts are found in nature when limestone fills the hollows left by fossil shells. How could you distinguish between a cast and a true fossil shell?*

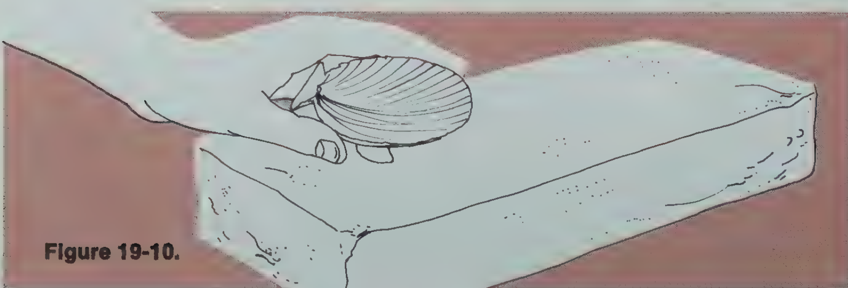


Figure 19-10.

Figure 19-11.

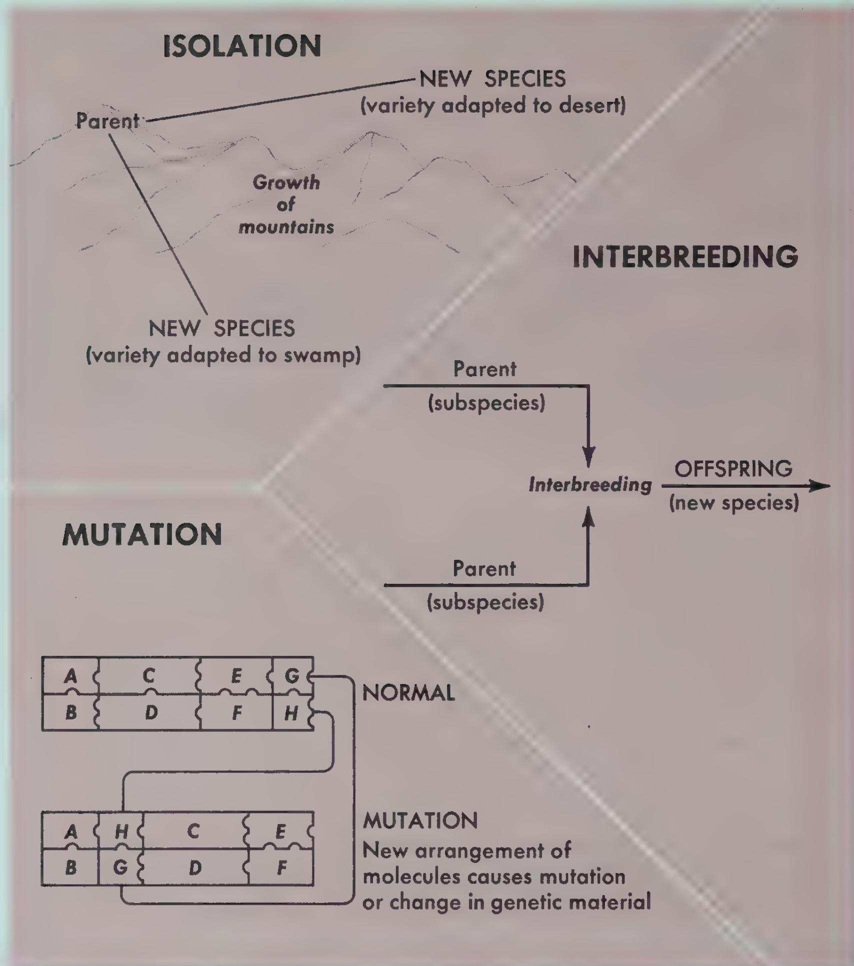
EXPERIMENT. Thoroughly coat a sheet of typing paper with white vaseline or cooking oil. Remove any excess oil from the paper. Light a candle and hold it below the paper so that the carbon from the flame coats the paper. Be careful not to burn the paper. Place a perfect leaf from a tree or bush on the carbon-coated side of the paper. Cover the leaf with a paper towel and press gently. Lift the towel carefully and then remove the leaf with tweezers. Place the leaf, carbon-coated side down, on another sheet of typing paper. Press with a clean paper towel. Carefully remove the leaf. You should have a perfect carbon impression of the leaf. Cover the impression with a sheet of thin plastic (sandwich wrap) and save for experiments in Section 20:6. Do you have a true fossil?

Rock layers that contain fossils are called *fossiliferous* (fahs i lif'e ras). Fossiliferous limestone is fairly common. Reef environments are especially favorable for the preservation of numerous kinds of marine organisms. Plants and soft-bodied animals may be preserved in soft muds or in layers of volcanic ash. But most preservation of organic material occurs in marine sediments, flood plains, or lake beds, because quick burial is most likely in such environments. Furthermore, oxygen is less abundant in the deeper parts of lakes or seas, and decay is less rapid than on land.

Fossiliferous rocks contain remains of ancient life.

Some fossils represent organisms that lived in a limited environment. Such fossils are known as **facies** (fae'shee eez) **fossils.** For example, certain life forms live in shallow water, but not in deep water. Other organisms live in fresh water, but not in seawater. Facies fossils are useful in understanding the conditions of deposition, as well as the sequence of events. For example, dinosaur bones indicate a land environment; bones of swimming reptiles indicate a marine environment.

Figure 19-12. Species may develop through isolation, interbreeding of subspecies, or mutations.



To use fossil dating efficiently, paleontologists first separate fossils into groups according to similarities or differences among them. The group most useful to paleontologists is called a species (spee′sheez). A **species** is a population of individuals that have similar characteristics, such as bone structure or surface markings. Although the individual members of a species are not identical, the living members can interbreed and produce offspring that have the same general characteristics. But even small differences among individuals may result in the development of new species by a series of gradual changes. One such change is an increase in size. Other changes may involve bone structure, eye position, or ear structure. Some changes have involved body covering. The changes that may occur are almost numberless. But most changes occur gradually, and if the fossil record is good, the changes can be traced from one geologic time division to another.

Figure 19-13. Throughout geologic time, life has become more complex and diversified. Note the complexity of the human skeleton as compared to the trilobite.

Reasons for change are not always the same. Sometimes a species is so isolated that its members can interbreed only with a limited number of individuals. Then any differences tend to become emphasized. Sometimes subspecies interbreed and they produce new varieties. Subspecies are difficult to define. In general, individuals that belong to a **subspecies** are slightly different from members of another subspecies, but all members of both subspecies can interbreed. When subspecies interbreed, slight differences give rise to new forms. **Mutations** (meu tae′ shuns) are changes that occur suddenly in certain offspring of a species. These changes cannot be predicted, but sometimes they are passed on to succeeding generations. Thus, isolation, interbreeding of subspecies, and mutations bring about changes in a species. Changes in both plant and animal forms have occurred throughout geologic time. Fossil records suggest that most changes are in the direction of an increasing number of kinds of animals and plants. Changes have also brought about an increase in the complexity of the more recent forms. For example, trees are much more complex than algae (al′jee) which are among the earliest known plant-like organisms. Backboned animals are much more complex than the jellyfish-like forms, or the trilobites that are among the earliest known multicellular animal forms.

Most fossil forms have developed from simple to complex forms.

Both physical changes and biological features in rocks are used to differentiate the long history of the earth into time units. The fossil record contains many examples of the extinction of certain species and the emergence of new species. Boundaries between time units are based on the life span of certain life forms. Such units contain varying numbers of years, and cannot be compared to the more common units of time such as hours, days, months, or years. Indeed, the life span of some species has covered only a few thousand years, while other species have lived for millions of years. But changes in life forms and patterns are useful for relative dating of geologic time.

Great changes in these life patterns often accompany major changes in the physical character of the earth's surface. Boundaries of eras are related to the uplift of mountain systems. But these boundaries are also dividing lines between the extinction of major groups of animals and the appearance of new groups. (Table 20–1.) In general, boundaries between eras mark times when continents were high above sea level. Oceans were mostly withdrawn from the land masses and erosion was rapid. Folded metamorphic and igneous rocks were worn down and reduced

Field Museum of Natural History
Artist, Charles R. Knight

Figure 19-14. During the Mesozoic Era, reptiles invaded all environments.

to sea level. Seas gradually flooded the continents, and younger layers of sediments were deposited above the eroded surfaces of the continents. Such breaks in the rock record are called **unconformities.** They are evidence of physical changes in the earth's surface. Above such breaks, rocks contain fossils quite different from those contained in older rocks.

Index or guide fossils must be abundant, widespread, and limited in time span.

In addition to dating rocks, fossils also provide information about the history of life on earth. Fossils that can be used to divide geologic time into small units are called **index fossils,** or **guide fossils.** Index fossils are remains of organisms that lived only a short time, but were found in many different regions of the earth. In a sequence of rocks, the older layers contain forms of life that are simple compared with the increasingly complex forms of the younger layers. The relative ages of layers are determined by the law of superposition. Then the ages of fossils are compared by determining the position of the fossil containing layer within the sequence of beds. However, in regions where rock layers are folded or faulted, fossils themselves may

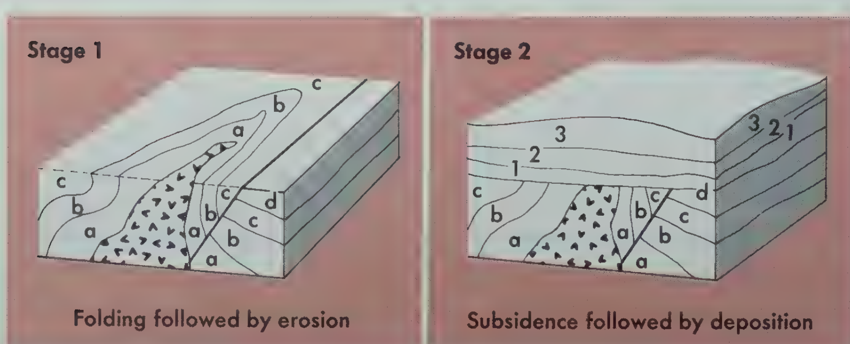


Figure 19-15. In Stage 1, rocks have been folded, uplifted, and eroded. In Stage 2, the folded beds of Stage 1 have been submerged and covered by younger sediments to form an angular unconformity.

be used to determine the relative ages of rock layers that have been overturned, or thrust over other layers. By comparing fossils found in the folded or faulted layers with fossils found in horizontal beds, complex rock structures often can be *correlated* (kawr′e laet ed), or matched, and their position within a sequence of beds can be determined.

19:6 Geologic Column

Stratigraphers and paleontologists have combined their efforts to determine the sequence in which sediments were deposited, then consolidated into hard rock layers. Correlation of rock layers from place to place is based on the law of superposition and on the type of fossils contained in the rock layers. In the latter part of the eighteenth century, William Smith, an English engineer, traveled through England and Wales. Smith found that he could recognize rock layers from one place to another, based on the fossils in the rocks. Smith mapped the locations of these fossils and later matched the fossils of England with those of certain rock layers in France. Eventually, the English rocks were correlated with rocks in Holland, Belgium, and other regions, as a result of comparison of similar fossils.

By worldwide correlation of fossils and rock layers, geologists have attempted to reconstruct a complete record of deposition from the beginning of time. This model of all deposition is known as the **geologic column.** A geologic column is only an estimate of the thickness of deposits, because erosion has removed much of the record. Geologists can only guess at how much of the total rock record has been lost. However, erosion has not removed rocks from all regions at the same time. While one region was undergoing erosion, another region was receiving deposition. Like solving a giant jigsaw puzzle, the geologist attempts to match rock layers in one region with rock layers in another region. Or he fits deposits from one layer into missing layers in some other place. Eventually, he assembles a sequence of rocks, from the oldest to the youngest, into a column that represents all the known records of deposition.

Based on the geologic column, rocks have been assigned positions in time. Most of the dating of the series of sample rocks is based on relative position in the column. But some absolute dates have been supplied by radioactive dating. Divisions of geologic time are known as the *geologic time scale.*

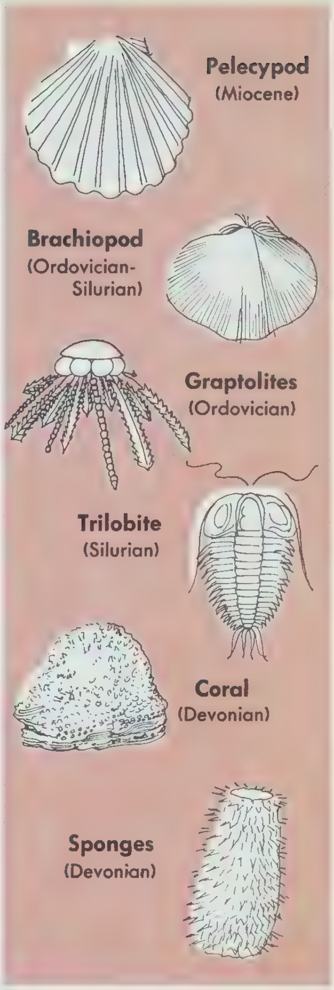


Figure 19-16. Each unit of geologic time has unique life forms, called index fossils, by which the age of the rock can be recognized.

Absolute dates may be determined for rocks that contain a radioactive element and its daughter products in measurable amounts.

MAIN IDEAS

1. An age of approximately 4.5 billion years has been estimated for the planet earth based on radioactive dating of meteorites. Fossils and rock layers are used in determining relative dates, and in determining position of rocks in the geologic column.
2. Suggested methods for determining earth's age include the rate of heat loss from molten rock, the rate of accumulations of salt in the ocean, and the rate of accumulation of sediments. None of these methods is accurate because they are all based on factors that cannot be measured precisely.
3. Decay of radioactive elements provides a satisfactory scale for determining the ages of some rocks.
4. Radioactive elements include uranium, thorium, potassium 40, and carbon 14 which decay spontaneously at a measurable rate (half-life) and produce daughter elements until a stable element is formed.
5. Radioactive dating requires that both the parent radioactive element and the stable daughter product be present in measurable amounts. A radioactive date indicates when minerals containing the radioactive element crystallized from a magma, or precipitated from a solution, or when an organism died. Oldest absolute dated rocks are in Africa; next oldest are in Canada.
6. Carbon 14 is used to date organic remains. Carbon 14 is maintained at a constant level in all living matter because it is renewed constantly until the organism dies. After death, decay of radioactive carbon occurs at a regular rate. Its half-life is 5,770 years.
7. Arrangement, or superposition, of rock strata indicates relative age of layered rocks.
8. Fossil records, tracks, impressions, molds, replacements, and preserved hard parts of plants and animals indicate that most species developed from simple to complex forms during geologic time.
9. Index or guide fossils are fossils that have a limited time span and widespread distribution. They are useful in correlation, and also in separating the geologic column into time units.

10. Mountain building helps divide geologic time into units. Such revolutions may have changed the environment to such an extent that many organisms could not survive, and new life forms developed.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

absolute date	index fossil
carbon 14	mutations
correlation	paleontology
crosscutting relationships	permineralize
daughter element	radioactive decay
facies fossils	relative ages
fossils	species
fossiliferous	stratigraphy
half-life	superposition

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. The salt method of age determination is used to determine relative dates.
2. Radioactive elements change into different elements in time.
3. Absolute dates are determined by fossil forms.
4. Daughter elements must be present to date minerals.
5. Some carbon 14 is present in all living organisms.
6. The age of the earth is judged to be approximately the same as some meteorites.
7. Man has existed on the earth for about 1 billion years.
8. Stable elements have lost their radioactivity.
9. Carbon 14 changes to nitrogen as it decays.
10. The earth is older than any member of the universe outside the solar system.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Scientists who specialize in age determination by study of rock layers are called (*paleontologists, stratigraphers, physicists*).
2. The age of the earth is calculated to be (*2.7, 3, 4.5*) billion years.
3. The method which seeks to determine earth's age by measuring thickness of deposits of silt, sand, and gravel is called the (*sedimentation, salt, heat loss*) method.
4. Uranium commonly is found in (*sedimentary, metamorphic, igneous*) rocks.
5. The oldest known rocks are found in (*Canada, Africa, Europe*).
6. Potassium 40 is found in (*sedimentary rocks only; metamorphic rocks only; metamorphic, igneous, and sedimentary rocks*).
7. Relative dates for igneous dikes may be determined by the law of (*uniformitarianism, superposition, crosscutting relationships*).
8. Age determination by carbon 14 is not reliable beyond (*5,770, 50,000, 1,000,000*) years before the present.
9. Geologists who specialize in the study of fossils are called (*paleontologists, stratigraphers, physicists*).
10. A radioactive element most useful in age determination of bones or wood is (*uranium 238, potassium 40, carbon 14*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The most accurate method of age determination is through the study of __?__ elements.
2. Rays given off during decay of the nuclei of atoms are __?__, __?__, and __?__ rays.
3. Dates which serve as a record of only a sequence of events are __?__ dates.

4. The rate at which radioactive elements decay spontaneously and become daughter elements is called their __?__.
5. A radioactive element which originates in the upper atmosphere is __?__.
6. The principle used to determine relative ages of layers in a series of undisturbed rocks is known as the law of __?__.
7. Rocks which contain many remains of past life are called __?__ rocks.
8. New elements which form during decay of radioactive elements are called __?__ elements.
9. Fossils which are preserved by permineralization or petrification are __?__ of one material by another.
10. If a fossil has a short time span, but is widespread, it makes a good __?__ fossil.

D. How and Why

1. What is the difference between relative and absolute dates of geologic age?
2. Would a fossil species which was abundant over a period of 400 million years be a useful index fossil? Explain your answer.
3. Why do only a few organisms become fossils after death?
4. Is petrified wood a fossil?
5. The last ice age began about 1 million years ago and retreated from North America 11,000 years ago. Could any of this time be dated by carbon 14?
6. Why are marine animals rather than land animals more likely to be preserved as fossils?
7. Tree trunks and leaves are often found in coal. What kind of environment has made their preservation possible?
8. Why are limestones rather than sandstones more likely to contain fossils?
9. Why are layers of volcanic ash unusually good indicators of time, as well as useful for relative dating of beds beneath them and above them?
10. How could you obtain dates for a sedimentary series of rocks cut by an igneous dike composed of granite? What kind of dates would you have for each rock?

INVESTIGATIONS

1. Report on the use of wood from campfires to determine some dates of rocks in the United States.
2. Report on the use of carbon 14 to date remains found in recent excavations in Mexico.
3. Make a list of animals of North America which should make good facies fossils.

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* Well-illustrated material.

The Geologic Time Scale

Using a combination of absolute dates and relative dates, geologists have constructed the geologic time scale. (Table 20–1.) The units of this scale are based on systematic correlation of sedimentary layers. These units of time are separated by the presence or absence of certain fossil forms, as well as by absolute dates. Geologic dating is not exact, because the time involved is so vast, and because some rock formations may have been removed.

20:1 *Geologic Time Units*

Geologic time, from its beginning to the present, is divided into two major units called *eons* (ee′ans). The oldest, called the **Cryptozoic** (krip ta zoh′ik) **eon**, includes all of the time from the formation of the planet earth to 600 million years before the present (B.P.). The second eon, called the **Phanerozoic** (fan e ra zoh′ik) **eon**, includes all of the time from 600 million years B.P. to the present.

Geologic time is divided into two eons, the Cryptozoic and the Phanerozoic.

The term Cryptozoic comes from two Greek words: *cryptos* (krip′ tohs), which means hidden or secret, and *zoion* (zoh′i on), which means animal. The name indicates that any life which may be present in Cryptozoic rocks is hidden. The second, or Phanerozoic, eon contains abundant evidence of past life. The term Phanerozoic comes from the Greek word *phaneros* (fan′ er ohs), which means visible. Thus, time is divided into two eons: in one, evidence of life is lacking; in the other, an abundant record of life is present.

Cryptozoic rocks contain few fossil forms.

The Cryptozoic eon cannot be subdivided into smaller units that can be correlated from one place to another. The Phanerozoic eon, based on the abundant fossil content, is subdivided

Rocks of Phanerozoic eon contain much visible evidence of past life.

Field Museum of Natural History
Artist, Charles R. Knight

Figure 20-1. Before life appeared on earth, the land was a barren waste.

into *eras*. Eras are further subdivided into *periods*; periods are divided into *epochs*. All units of the Phanerozoic are subdivided into smaller units on the basis of index fossils.

Extinction of old life forms and emergence of new ones are recorded in the rock layers. Changes in life forms commonly are associated with changes in the elevation of continents. Such changes are reflected in the sedimentary deposits, as well as in the life forms. When worldwide mountain systems are formed, their emergence is accompanied by climatic changes, and by the withdrawal of the sea from the land. Marine animals have less living area, but land animals have more room for expansion. These are some of the reasons why changes in the fossil record are associated with mountain building events. Major mountain building, however, covers millions of years. Although it affects many areas of the world, these areas are not all uplifted at exactly the same time.

Periods usually are the smallest divisions of geologic time that can be correlated on a worldwide basis. But paleontologists find it convenient to divide periods into epochs, or into even smaller units called *zones*, as an aid to assembling the geologic column for a local area. Zones are grouped into epochs, epochs are grouped into periods, and periods are grouped into eras. Each larger time division includes a larger group of animals and plants that are characteristic of that particular time. Such groups of life are known as **fossil assemblages.** The larger

the number of fossils that make up an assemblage, the better is the chance that some of them will be found in another region. If the same fossils are found in more than one region, the areas can be correlated. Recall that facies fossils differ from place to place because they live only in a special kind of environment. But sometimes even facies fossils are carried by transporting agents into a location where they are mixed with another fossil assemblage. For example, during a storm, deepwater fossils may be carried to shore. If strong winds blow offshore, shallow water forms may move into deep water. Such movements help to assemble forms that live at the same time, even though the forms ordinarily do not live in the same environment.

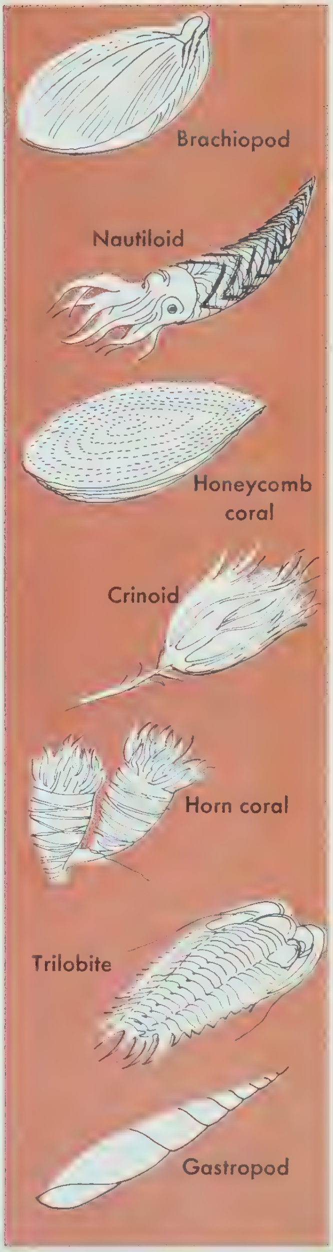


Figure 20-2. Typical fossil assemblage of the Silurian sea bottom.

20:2 *Cryptozoic Eon*

Rocks belonging to the Cryptozoic eon are present on every continent. The region in which such rocks are exposed at the surface is called the **continental nucleus.** But much of the Cryptozoic rock record is buried beneath younger rocks, or has been eroded away. Cryptozoic history is difficult to interpret from the rocks, because most of the rocks have been subjected to extreme metamorphism. Again and again in this eon, mountains were uplifted. Then most of the younger rocks were eroded, leaving only the metamorphosed mountain roots. Even if fossils had been present in the rocks, in most regions it would be impossible to recognize them now.

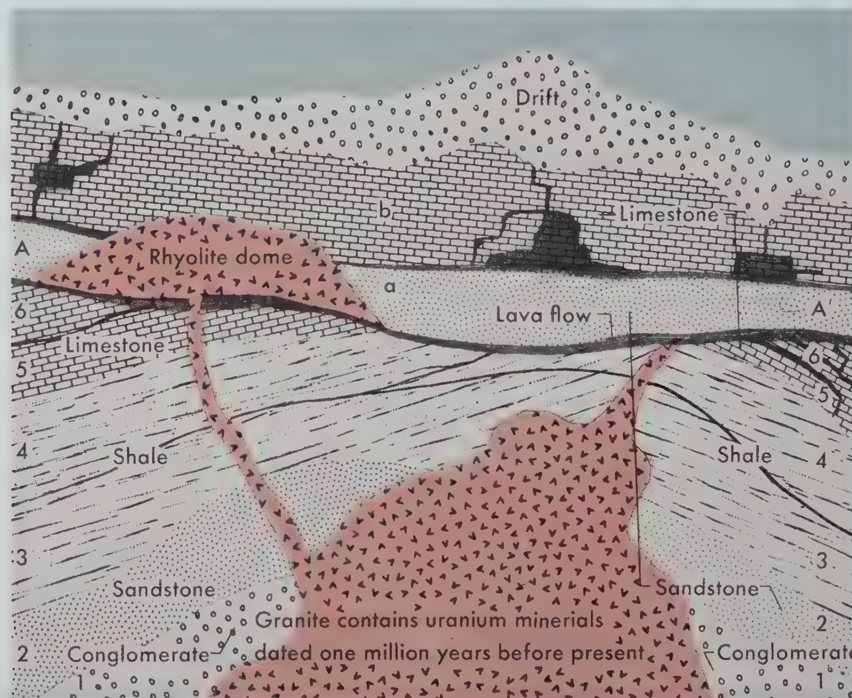
Subdivision of the Cryptozoic eon on the basis of fossils is impossible. Thus, the first 4 billion years of earth history cannot be separated into meaningful units of time. Preservation of organic matter has occurred only during the last 600 million years of earth history. In the preceding 4 billion years, only a few microscopic plant fossils, such as algae, were preserved. Consequently, little is known about life in the Cryptozoic eon. In fact, paleontologists have hesitated to state that any life except the most primitive protists existed before the Phanerozoic eon. But in 1947, some impressions of soft-bodied organisms were discovered in Cryptozoic rocks of Australia. In many respects, these impressions appeared to be ancient forms similar to modern jellyfish. A few stem-like prints suggested that algae or seaweeds also were present in the Cryptozoic. Although some plants and animals may have been present in the Cryptozoic eon, it appears that fossils are rare. Cryptozoic life apparently lacked hard parts. Metamorphism, to which much of the rock was subjected, tends to erase the presence of fossils.

Cryptozoic organisms may have had no hard parts that could be preserved.

Rocks of the Canadian Shield area belong to the Cryptozoic eon, as do the rocks at the bottom of the Grand Canyon. But without fossils, it is impossible to correlate rocks from these two regions. Nor can they be correlated with rocks of Australia or any other continent. All of these rocks are placed in the Cryptozoic eon, because all of them lack fossils. When absolute dates are available for more of the Cryptozoic rocks, paleontologists and stratigraphers may be able to subdivide this long unit of geologic time into smaller units. Rocks of the Cryptozoic are often referred to as *Precambrian*, or belonging to the time before the Cambrian period. The Cambrian period is an important time marker because rocks since the beginning of the Cambrian period contain fossils. Most Precambrian rocks are metamorphic or igneous, but sedimentary rocks are present in a few regions.

Rocks of Precambrian time are mostly metamorphic.

Figure 20-3. Seas have advanced, withdrawn, and advanced repeatedly throughout geologic time, leaving a complex record in their deposits.



Problem

Write the geologic history of the region illustrated in Figure 20–3. Indicate which beds are marine, which are continental, and which are igneous. Also indicate which dates are absolute and which are relative.

20:3 Phanerozoic Eon

The Phanerozoic eon began about 600 million years ago, and continues today. Phanerozoic time is divided into three eras: **Paleozoic** (pae lee a zoh′ik), which means ancient life; **Mesozoic** (mes a zoh′ik), which means middle life; and **Cenozoic** (see na zoh′ ik), which means recent life. Boundaries of eras are associated with geologic revolutions, or mountain building events. But the division into eras is based on the extinction of certain life forms. Volcanic activity and climatic or environmental changes which commonly accompany mountain building may have influenced the disappearance of certain life forms. It cannot be determined which changes in the environment influenced the changes in life. It is even possible that the disappearance of animals and plants typical of a geological era was influenced by causes that paleontologists cannot interpret today.

Phanerozoic eon covering 600 million years is divided into Paleozoic, Mesozoic, and Cenozoic eras, on the basis of the contained fossils.

Geologic revolutions, or mountain building, commonly mark transitions from one era to the next.

Like the era, smaller divisions of geologic time also are based on the extinction of certain life forms and the appearance of new forms. The record of all animals and plants that lived and died during the 600 million years of the Phanerozoic eon is incomplete. But enough evidence is available to subdivide the eon into smaller units.

Eras are divided into periods based on changes in life forms.

Problems

Refer to Table 20–1 to answer these questions.

1. If the time covered by the Cenozoic era is accepted as 65 million years, approximately how many million years does the Paleozoic era represent? How many million years does the Mesozoic era represent?
2. Using the estimated age of the earth, approximately how many years does the Cryptozoic eon represent?
3. If you use the scale of 1 in. to represent the time covered by the Cenozoic era, approximately how many inches would represent each of the following: Mesozoic era, Paleozoic era, Phanerozoic eon, and Cryptozoic eon?

20:4 Paleozoic Era

With the beginning of the Paleozoic era, earth history becomes somewhat easier to interpret. The era is divided into seven periods, each of which is named for the geographic location in which it was first described. Because the earliest field

studies were conducted in Wales and England, the oldest periods have British names. Adam Sedgwick, an English geologist, and Sir Roger Murchison, another English scientist, first described the lower Paleozoic sections and named the Cambrian and Silurian periods. The Ordovician was named by Charles Lapworth.

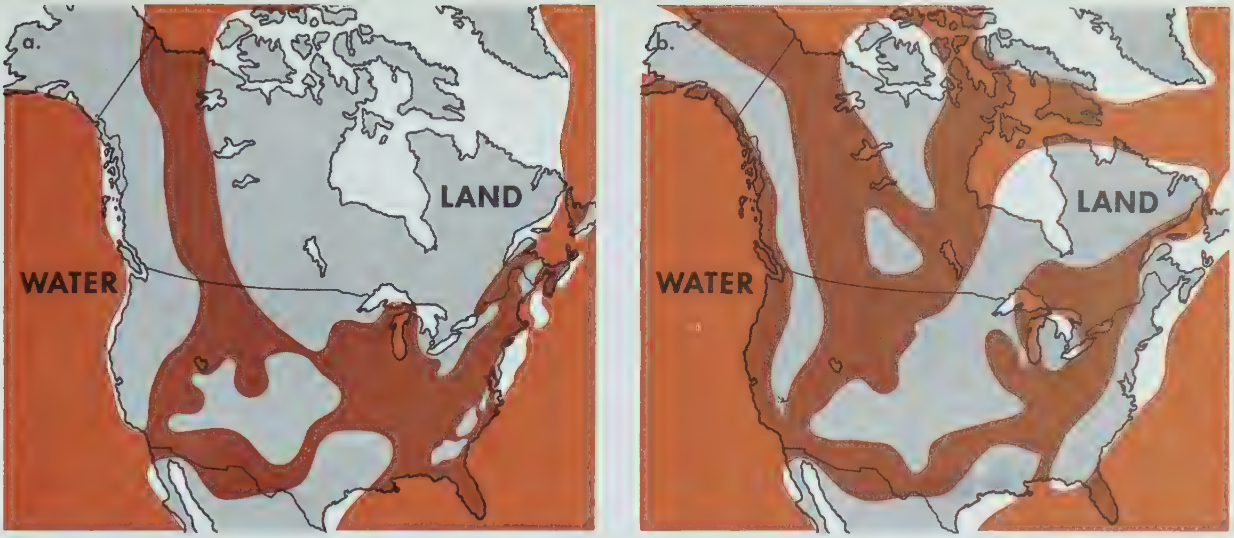
Paleozoic era is divided into seven periods named for the regions where their rocks were described first.

The **Cambrian,** oldest of the periods, is given the old Roman name for Wales. **Ordovician** (awrd a vish′an), the next oldest, and **Silurian** (sie luhr′ee an), the third oldest, are named for ancient tribes of Wales. **Devonian** (di voh′nee an) is named for Devonshire, England. The next two period names come from locations in the United States. **Mississippian** is named for exposures along the Mississippi River, and **Pennsylvanian** is named for exposures in the mountains of Pennsylvania. **Permian** (pur′mee an) is named for a province in Russia where these rocks are exposed.

Earliest known records of animal life are marine **invertebrates** (in vert′e brats), or animals without backbones. Invertebrates probably lived in shallow water, near the shore. These ancient forms were soft-bodied, but had a covering of *phosphatic* (fahs fat′ik) material similar to your fingernails. Modern shrimp and soft-shelled crabs have similar coverings. Two important representatives of the ancient invertebrates were trilobites (trie′la biets) and brachiopods (brak′ee a pahds). *Trilobites* are distantly related to crabs and lobsters. *Brachiopods* resemble clams, but belong to a different subdivision of animal life.

Fossils are well preserved in Cambrian rocks of North America where deposition was undisturbed.

During the early Paleozoic era, shallow seas invaded the continents, and environments favorable to abundant marine life existed over thousands of square miles. In many regions, the Cambrian period was one of quiet deposition. Animals lived, died, and were buried in the rocks. Sometimes whole bodies were kept intact. But, because trilobites were jointed animals, their heads often became separated from their bodies after death. Rocks that contain numerous trilobite bodies and heads jumbled together are called *trilobite hash.* Most of the Cambrian fossils consist of trilobite and brachiopod coverings, but in one locality in British Columbia, the *Burgess shale* preserved not only the coverings of animals but also carbon imprints of soft bodies. A great variety of life from the Cambrian period is preserved in this shale. The muds which formed the Burgess shale must have been deposited in a deep basin where there was little circulation to disturb the organisms that had accumulated.



During the Ordovician period, calcitic shells replaced phosphatic coverings in most of the brachiopods. Calcitic shells were preserved in greater numbers than the earlier softer coverings. As the number and varieties of animals increased, limestones were deposited that consisted almost entirely of preserved shells. During the Silurian period, great limestone reefs were built by corals and other animals that found the reef a favorable environment for food and protection.

Figure 20-4. Seas advanced over the interior during Cambrian (a.) and Ordovician (b.), but retreated during the Taconic Mountain uplift on the East Coast.

Figure 20-5. During the Ordovician period, straight shelled cephalopods, snails, and trilobites were a common assemblage of marine animals.

Field Museum of Natural History—Artist, Charles R. Knight

Field Museum of Natural History
Artist, Charles R. Knight

Figure 20-6. Silurian corals exposed along the shore zone.

Figure 20-7. (a.) All of North America, except the evaporite basin of Michigan and New York, emerged from the sea by the end of Silurian. (b.) At the close of the Paleozoic, the continent, except the Texas evaporite basin and the Pacific geosyncline, emerged again.

Changes in climate and environment, as well as major changes in both the plant and the animal kingdoms, occurred during the Devonian period. Mountain building caused seas to retreat from the land and to disappear from many regions. During this time, land plants, which had appeared during the Silurian period, developed into large forms. The earliest trees are found in rocks of the Devonian period. Eventually, new varieties of vegetation covered the exposed, uplifted land areas.

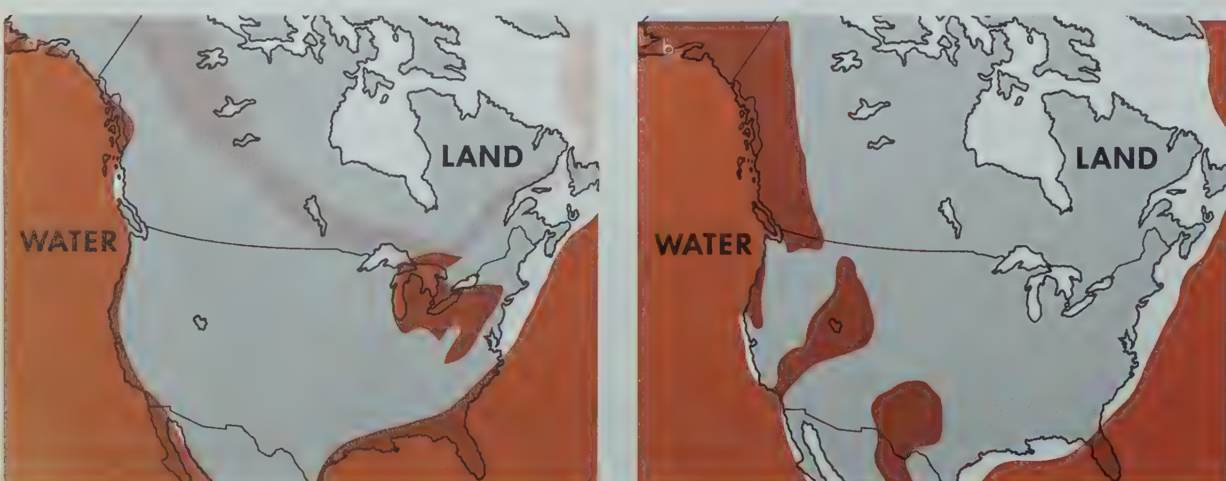


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Figure 20-8. Vegetation characteristic of the Devonian forests of western New York including horsetail rushes, tree ferns, and early leafless plants.

These new land plants, which resembled giant ferns and marsh plants, were forerunners of today's vegetation. When plants appeared on land, animals found a new environment. But until land plants were available for food, animals either did not venture upon the land, or if they did, they died from starvation.

During the Silurian period, the transition from marine animals to land animals occurred. Fish, the first backboned animals, had appeared at least as early as the Ordovician period, but they became the dominant occupants of the sea during the Devonian period. One kind of fish developed a lung that allowed it to survive out of water. In addition, some of these fish had fins that would support their weight. Because they could obtain oxygen and food and could move about on land, these lobe-finned fish were able to adapt to the land environment. Lobe-finned fish were ancestors of amphibians (am fib′ee ans).

Amphibians cannot live far from water, because their eggs must be laid in water. Even adult amphibians must spend part of their time in water or lose their body fluids. Modern varieties of amphibians include frogs and toads. Amphibians have not been the dominant life form since the end of the Paleozoic era.

During the late Paleozoic era, one variety of amphibian developed the ability to survive without returning to the water. The first clue to the development of this new variety of animal was the discovery of an amniotic (am nee aht′ik) egg along with amphibian-like bones. An *amniotic egg* has a hard, protective outer covering surrounding a watery material which nourishes the *embryo* (em′bree oh), or baby. This new development in reproduction of offspring meant that the adult no longer had

Figure 20-9. Bones in the fish's lobe fin appear to be forerunners of the amphibian's limb bones.

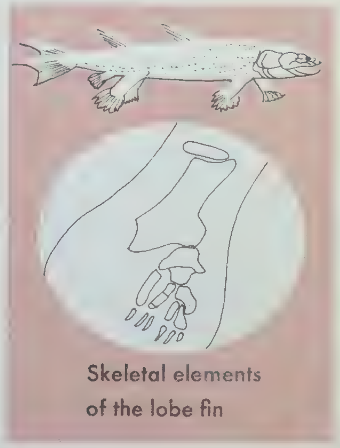

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Figure 20-10. Fin-backed and other reptiles of the Permian period were mostly awkward, slow-moving animals.

to return to the lakes, swamps, or sea to produce its young. Amphibians gave rise to *reptiles*, the name given the new variety of animals that produced the amniotic egg. Along with this change in reproduction, reptiles developed hard scales that prevented the evaporation of their body fluids. These two changes allowed reptiles to roam the land except in frigid zones. Like fish and amphibians, reptiles are cold-blooded and must live in warm climates to maintain their body temperature.

During late Paleozoic time, fish dominated the seas, and amphibians or reptiles dominated the land. Many varieties of invertebrates were present, as they are today, but invertebrates were no longer the dominant life forms. All trilobites and nearly all amphibians became extinct at the end of the Paleozoic era. Numerous changes in the invertebrate groups also occurred. For these reasons, the Permian period is sometimes referred to as the *period of the great extinction.*

In addition to the changes in the life forms, physical changes in the earth also occurred toward the end of the Paleozoic era. Vast swamps, much like the Everglades of Florida, covered the interior of continents during the Pennsylvanian period. After burial, vegetation of these swamps became the great coal fields of the world. Mountains rose higher and higher around the edges of continents and prevented moisture-laden winds from reaching the interior. During the Permian period, desert conditions accompanied uplifting of mountains. Land vertebrates and land plants that survived were those that adapted to the new environment. As their living area increased,

land animals increased in numbers and variety. But as the seas withdrew from the land, marine animals were crowded into smaller and smaller areas and many forms became extinct.

By the end of Paleozoic time, continental land masses were no longer submerged. Along the eastern coast of North America high mountains, now known as the Appalachians, had arisen. Extensions of these mountains stretched as far south and west as the area which is now Texas. Mountain chains probably were also present along the west coast of North America. Mountain ranges joined Europe and Asia into one vast land mass. A large part of South America emerged from the sea, as did the continent of Australia. Great changes marked the end of the 370 million years of the Paleozoic era.

Continents were raised and mountain chains were formed as Paleozoic era ended and Mesozoic era began.

20:5 *Mesozoic Era*

The middle era of earth history covers less than half as much time as the Paleozoic era. The Mesozoic era is divided into three periods: Triassic (trie as′ik), Jurassic (juh ras′ik), and Cretaceous (kri tae′shus). The **Triassic period** is named for exposures in Germany. **Jurassic** is named for the range of Jura Mountains which borders France. **Cretaceous** is named for the great exposures of chalk which are characteristic of many rocks formed during this time. Possibly the most famous of the Cretaceous chalk beds are the chalk cliffs of Dover, England.

Mesozoic era is divided into Triassic, Jurassic, and Cretaceous periods.

During the Mesozoic era, climatic changes occurred as mountains were worn down and the land was once more reduced to near sea level. Over much of the earth, an arid climate existed during Triassic time. Gradually, conditions changed, and by

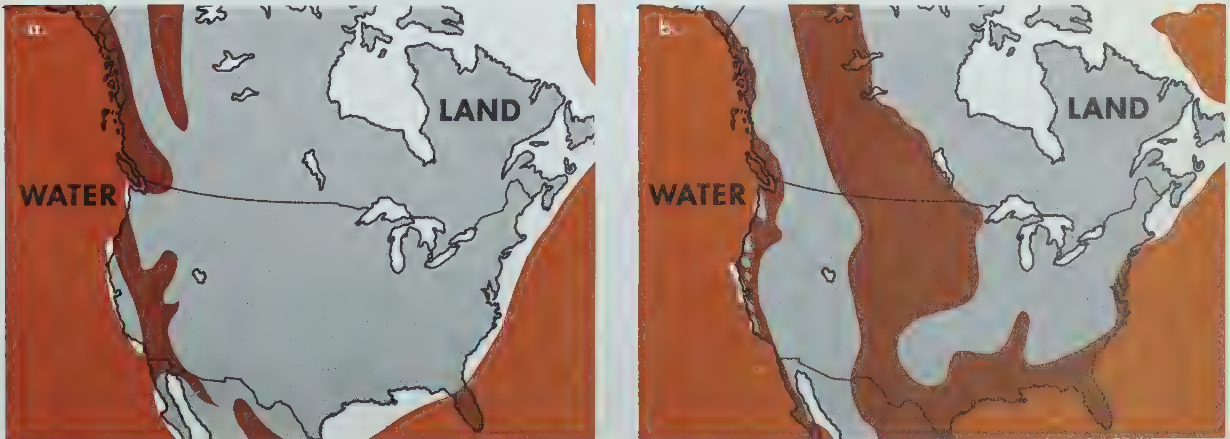


Figure 20-11. **During the Triassic period (a.), the emergence begun in Permian time continued. Seas returned to the interior during the Cretaceous period (b.) for the last great submergence.**

Erosion lowered land and allowed seas to cover large areas during the late Cretaceous.

the Cretaceous period, a humid climate had returned. Seas reinvaded many land areas during Cretaceous time. East of the Mississippi River, the land remained above water except for a narrow border along the Atlantic Coast and the Gulf Coast. The western region was flooded from near the present location of the Mississippi River almost to the Pacific Ocean.

Great changes in animal and plant life accompanied changes in the Mesozoic environment. Plants of the Paleozoic era had been types that were adapted to a humid climate. New plant groups that developed during the Mesozoic era were more adaptable to varied environment. The first **angiosperms** (an′jee a spurms), or flowering plants, had developed by Cretaceous time and had become the dominant type of vegetation. Angiosperm seeds have a protective covering and they can survive hot, cold, wet, or dry seasons. Even though the parent plants died, the seeds could survive for long periods of time, and eventually they could take root and continue the life of the group. These improvements in survival of offspring caused a rapid spread of angiosperms into all regions.

Many invertebrates also developed new forms and greater variety. One of these groups, the **ammonites** (am′a niets) is abundant in rocks which were deposited during the Mesozoic era. Ammonites could float on the sea, and thus were distributed over wide areas. Because their shell markings are distinctive, ammonites can be matched from Europe to Mexico to the United States. Paleontologists are able to divide the Mesozoic era into many zones based on ammonite index fossils.

Reptiles, especially dinosaurs, dominated the animal kingdom during Mesozoic time.

Reptiles were the most characteristic and interesting of the Mesozoic animals. The dominant group of reptiles has been named **dinosaur** (die′na sawr), which means terrible lizard. Some varieties of dinosaurs were extremely large and became masters of the animal world. Some dinosaurs were *carnivorous* (kahr niv′ a rus), or flesh-eaters; others were *herbivorous* (er biv′ a rus), or plant-eaters. Paleontologists have reconstructed the skeletons of many dinosaurs and, from the structure of the jaws and teeth, have determined the nature of the dinosaurs' diets.

Brontosaurus was a vegetarian dinosaur; Tyrannosaurus was a carnivorous dinosaur.

Brontosaurus (brahnt a sawr′us) was 60 ft to 70 ft from nose to tail and weighed about 30 tons. Brontosaurus lived in marshy lands and was herbivorous. It is difficult to imagine how they found enough plants for their enormous needs. *Tyrannosaurus* (ta ran a sawr′us) was the largest carnivorous

land animal of all time. Tyrannosaurus was about 20 ft tall and 50 ft long and weighed about 10 tons. Brontosaurus could obtain food in the swamps and thereby conserve energy, but tyrannosaurus had to hunt food. Many small dinosaurs must have been required to satisfy tyrannosaurus' hunger.

Field Museum of Natural History
Artist, Charles R. Knight

Figure 20-12. Brontosaurs, plant-eating dinosaurs of the Jurassic, probably spent much time in water in order to support their enormous weight of 30 to 40 tons.

Figure 20-13. Tyrannosaurus, the greatest of the Cretaceous carniverous dinosaurs, challenges Triceratops, the horned dinosaur.

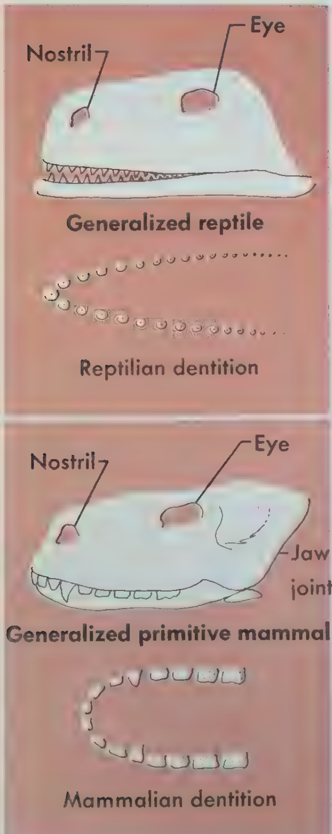
Field Museum of Natural History
Artist, Charles R. Knight

Reptiles are ancestors of both mammals and birds.

Dinosaurs are not the only reptiles for which the Mesozoic era is famous. *Birds* and *mammals* developed from their reptilian ancestors during the Mesozoic. Reptiles became so numerous and so varied that they inhabited all environments. Some of them became flying reptiles. Others entered the sea and developed paddle-like feet or fins. Like the modern whale, which is a mammal, most reptiles of the sea looked more like fish than like reptiles. However, their dental and skeletal characteristics indicate that they were indeed reptiles and not fish.

One of the most interesting finds ever made by fossil hunters was the discovery of the link between reptiles and birds. The skeleton of this fossil looked like that of a flying reptile. But some perfectly preserved specimens had retained their feathers and left their imprints in the enclosing rock. Feathers had replaced scales on this variety of animal. Thus, it was akin to both reptiles and birds.

Figure 20-14. Both shape and number of teeth differentiate the mammalian jaw from the reptilian jaw.



Another interesting change occurred in Mesozoic life in a group of reptiles that developed teeth with a variety of shapes. Reptiles had had teeth in the shape of an overturned cone. But the new group of animals had some teeth that resembled modern molars, some that looked like canine teeth, and others that were like the incisors of today's mammals. Another distinctive characteristic of this new reptile group was the position of their limbs. Instead of extending from their sides, as do the legs of crocodiles, the legs of this new group were attached under their bodies like the legs of mammals today. These ancestors of modern mammals were very unimportant in the Mesozoic, but they survived. Because of their mouse-like size, tyrannosaurus probably overlooked them in his search for food.

Like the Paleozoic era, the Mesozoic era ended with the extinction of many groups of animals. Dinosaurs disappeared, as did the flying reptiles and the marine reptiles. The surviving varieties of reptiles include turtles, snakes, lizards, and crocodiles. The importance of modern reptiles, compared with the dominance of the Mesozoic dinosaurs, seems insignificant in today's animal populations.

At the end of the Mesozoic era, the continents emerged once more and the seas withdrew from much of the submerged land. Mountain chains were uplifted along the borders of the Pacific Ocean in both North America and South America. Mountain ranges rose in other continents during this time. Many new life forms appeared and replaced extinct forms of Mesozoic life.

Field Museum of Natural History—Artist, Charles R. Knight

Figure 20-15. Flying reptiles among the Cycad trees illustrate two life forms of the Jurassic period.

Figure 20-16. Marine reptiles of the Mesozoic included the long-necked plesiosaurs and the finned ichthyosaurs.

Field Museum of Natural History
Artist, Charles R. Knight

20:6 Cenozoic Era

Cenozoic is divided into two periods, Tertiary and Quaternary.

The Cenozoic era is divided into only two periods, the **Tertiary** (tur′shee er ee) and the **Quaternary** (kwaht′er ner ee). These names have no particular meaning in the modern geologic time scale. The Cenozoic era began when ammonites and dinosaurs had disappeared. Rapid changes in the life of the Cenozoic followed and many new varieties appeared. Continents were enlarged and uplifted, bringing about the present distribution of land and sea, mountains and plains. The greatest changes during the Cenozoic occurred along the borders of the Pacific Ocean and at the present sites of the Alps and Himalaya.

Mammals have dominated the earth since the beginning of the Cenozoic era.

New life forms became prominent as the environment changed. The dominant marine invertebrates were members of the snail, starfish, and clam groups. Birds dominated the air; mammals dominated the land; fish still dominated the sea. Like the reptiles of the Mesozoic, the mammals adapted to all environments. Some mammals returned to the sea; others learned

Figure 20-17. By Miocene time, the continent of North America had emerged almost as it is today.

Field Museum of Natural History—Artist, Charles R. Knight

Figure 20-18. During the Pleistocene, the Australian kangaroos were giants compared to their modern descendents; Pleistocene wombats were the size of the modern rhinocerous. Both kangaroo and wombat are marsupials unique to Australia.

to fly. Whales and porpoises are mammals of the sea; bats are mammals of the air.

Because birds and mammals are warm-blooded animals, they could invade land environments which the reptiles could not tolerate. The mammals are the only vertebrates which bear their young alive and suckle their young. Thus, the mammal was better able to survive.

During Cenozoic time, many land areas became isolated. Australia and South America were separated from other land masses and, thereby, were cut off from the general trends of mammal development. Several unusual **marsupials** (mahr seu′ pee als) still exist in Australia. Female marsupials have a pouch in which they carry their young. South America also had a unique population of marsupials. In the late Cenozoic era, the

Animals from North America migrated to South America when a land bridge was formed. Southern forms were eliminated as a result.

Isthmus of Panama emerged from the sea. Then animals from North America moved south across this strip of land and entered South America. The North American animals occupied the South American continent, and the unique groups originally living in South America disappeared.

It is difficult to determine why the invading animals from North America were more successful at survival in South America than the native animals. Perhaps animals migrating from their northern homelands had already had to adapt to new climates and new kinds of food. Or perhaps weaker groups had not survived the migration. Whatever the reason, the animals from the north dominated South America and most of the South American animals became extinct. Only a few, such as the armadillo (ahr ma dil'oh), moved northward and found a new place to live. Armadillos now inhabit much of Southwestern United States.

PROBLEM

Make a chart similar to Table 20–1, but allow more space for each geologic time division. Indicate where each of the fossils in Figure 20–19 belongs. If possible, place each fossil in the correct period as well as in the correct era or eon.

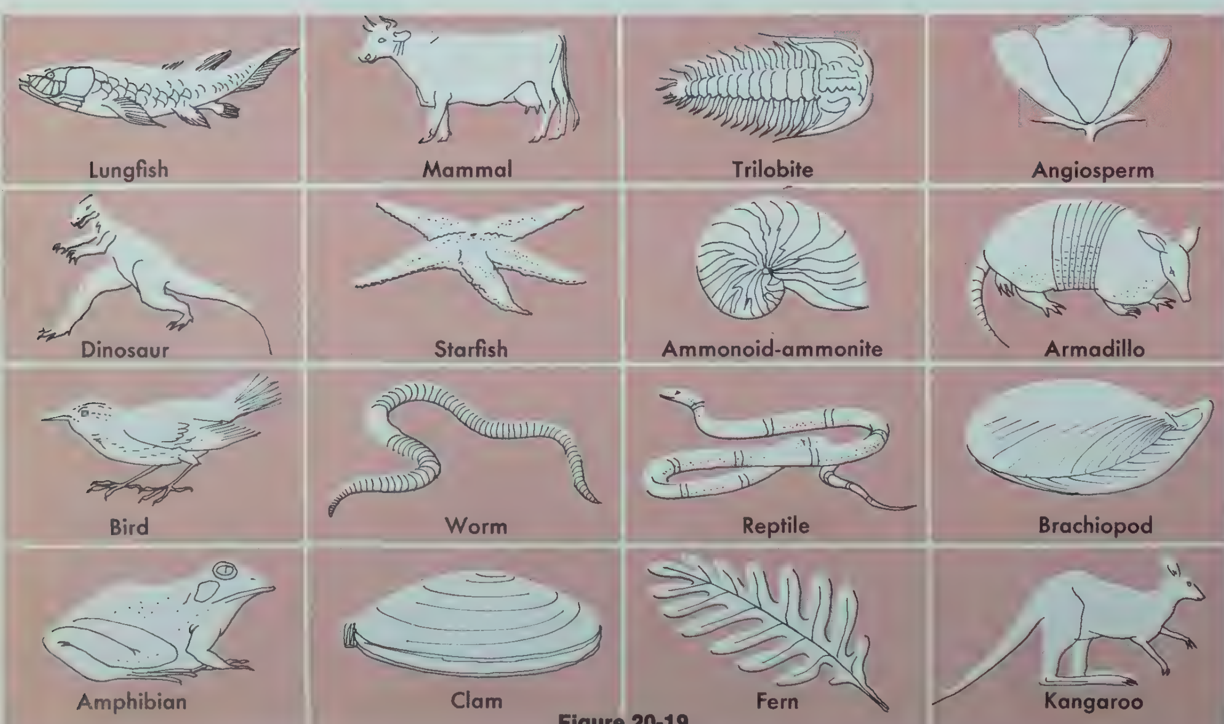


Figure 20-19.

Field Museum of Natural History
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Figure 20-20. Flesh-eating birds, as well as mammals, were trapped in the La Brea tar pool near Los Angeles, California, during the Pleistocene epoch.

A major event of the Cenozoic era was the spreading of a continental glacier from the region of Hudson Bay in North America, south to the present location of the Ohio River. In Europe, the ice covered much of what is now Scandinavia, Scotland, Germany, and Russia. This great ice age was present during the **Pleistocene** (plie′sta seen) **epoch**, the geologic time in which you are living. Moraines mark the southern boundary where ice once stood. Just north of the moraines, deposits of drift and till represent material which was scraped from the surface of the region to the north. Most of Canada was scoured and scraped by glaciation.

Figure 20-21. Remains of mammoths have been found from Siberia across North America. About 12 feet high, with long curved tusks and a woolly coat, the mammoth was characteristic of the Ice Age.

Field Museum of Natural History
Artist, Charles R. Knight

First indications of man's presence appear during the ice age in the Pleistocene epoch.

Fossil remains indicate that early man's diet was varied, that he could see in three dimensions, and that he walked erect.

During the ice age, man left his first marks upon the land. His stone implements are clues to man's presence at a time for which there is no other record. The history of early man has been reconstructed from an extremely small amount of evidence. Occasionally, nearly complete skeletons have been found. But more often, only a few skulls or thigh bones were preserved. Most of our understanding of early man's appearance is based upon skull and thigh bones. Position of eye sockets in the skull suggests that man's eyes were adjusted to seeing three dimensions better than other animals. Length and shape of thigh bones show that early man walked erect. Because teeth material resists decay better than bones, much of the information about early man is based on fossil teeth. From these fossils it is evident that early man could eat either flesh or grains as he does today. Short canine teeth indicate that man did not tear his food as some flesh-eaters do. Grinding molars indicate his ability to chew grains and other relatively hard materials.

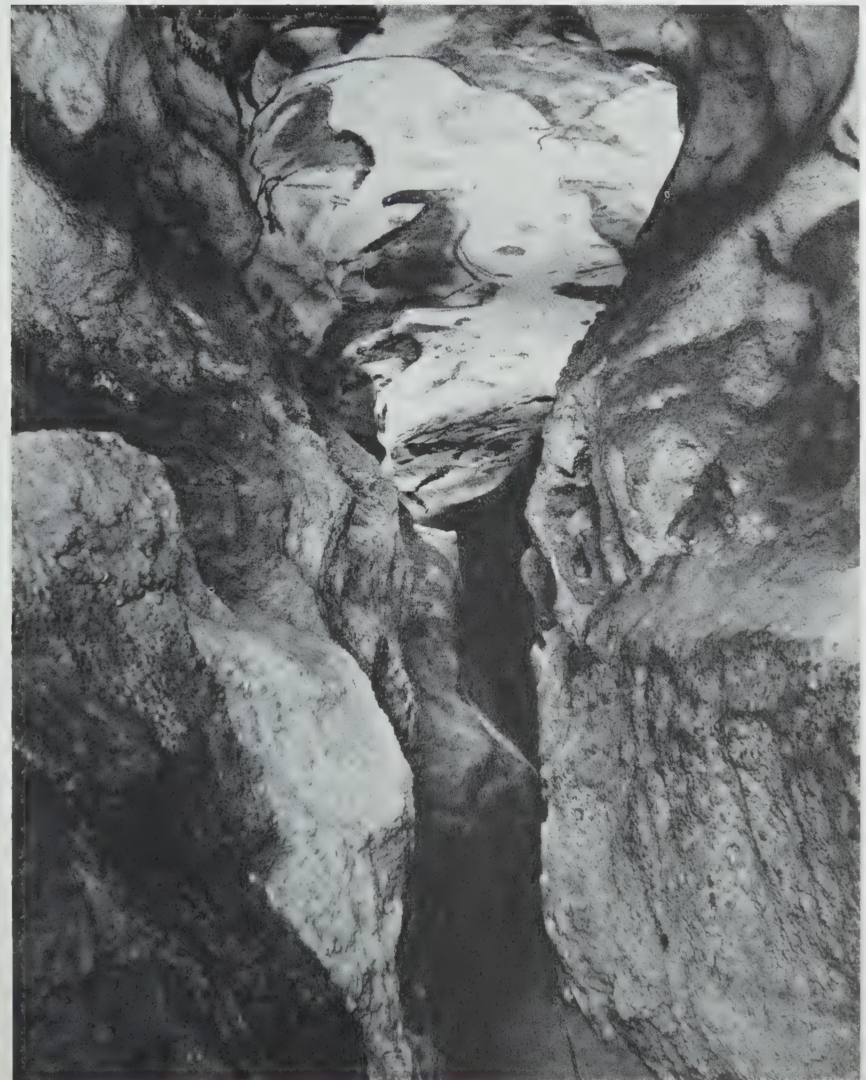
Many scientists are searching for more remains of early man. The British anthropologist, Dr. Louis S. B. Leakey, has made many interesting discoveries in Olduvai Gorge in present Tanzania. Dr. Raymond Dart and Dr. Robert Broom also have found fossils of man's ancestors in limestone quarries of South Africa. But the most complete record of man began in the caves of France. About 40,000 years ago, Cro-Magnon (kroh · mag′ nan) people lived in this area. They left paintings of bulls, horses, antelope, and reindeer on the walls of the cave homes. These pictures tell much about Cro-Magnon man's way of life. Awls, needles, knives, and other tools found in the caves show that these early ancestors had reached a high level of development. Fortunately, they lived in caves that remained dry. Therefore, records of their culture have been preserved.

Rock layers contain records of events and inhabitants of the earth. Uplift, erosion, and deposition leave their marks. Volcanic activity, intrusions, and mountain building events are recorded. Sediments preserve the history of advances and withdrawals of the sea from the continent. Fossils in caves and on flood plains may indicate the presence of land animals. But many questions about earth history remain unanswered. Although each generation adds new understanding, much remains to be discovered.

Earthquakes on the western coast of North America indicate that we still live in a period of mountain building. Thickness of sediments in the Gulf Coast region suggests the presence of a

geosyncline that some day may be uplifted into a young mountain chain. Many scientists believe that glaciers will advance across the land. Just when such events will occur cannot be predicted. Mountains will be worn down, seas will invade the land, and new mountains will be uplifted.

Severinus advised his students to "search the valleys, the deserts, the shores of the seas, and the deepest recesses of the world." He was suggesting the methods by which scientists attempt to unravel the puzzle of the history of the earth. Thousands of other students have followed Severinus' advice since he first told his students to observe their world.



Tourisme—Courbeix Courtesy France Actuelle

Figure 20-22. Early man left a record of his environment and artistic ability in some of the caves where he sought shelter. This Paleolithic painting is in the Lascaux Cave.

EXPERIMENT. Examine a collection of fossiliferous rocks of various sizes and kinds. Look for fossil clues such as footprints, carbon imprints, casts, molds, or replacements. Some true preservations also may be present.

Are the shells complete or broken? What do complete shells indicate? What do broken shells indicate? Are the shells in fine sediment or coarse sediment? If there are any casts, of what material are they formed? Compare the hardness of the shells to the hardness of the casts. How can you distinguish casts from preserved shells? How do the fossil imprints differ from the carbon imprint you made in Section 19:5?

Examine petrified wood samples. Are there any fossils? Compare the petrified wood to a block of natural wood. How do they differ?

EXPERIMENT. Obtain several specimens of fresh leaves and flowers. Sprinkle borax or baking soda on a pad of paper towels. Arrange the specimens so that all of the surfaces touch the borax or soda. Cover the leaves and flowers with a thin layer of borax or soda, and place two or three paper towels over the specimens. Pile several heavy books on the covering towel and leave them in place until the specimens are completely dry. Describe their color and appearance.

What is the purpose of the borax or soda? What type of fossil do the pressed leaves and flowers represent? Compare these fossils with the carbon imprint you made in Section 19:5. Would the specimens be the same if they had been buried in mud or silt?

ACTIVITY. Collect leaves from as many different environments as possible. In most regions, it should be possible for you to obtain a variety of leaves from places such as swamps, gardens, and vacant lots. The leaves should include a flat-veined leaf, such as maple, oak, or elm; an African violet leaf (thick and moist); a fern leaf; pine needles; heads of grasses such as rye grass or wheat; a geranium leaf; and a hollow stalk, such as reed, bullrush, or miniature bamboo.

Mount the leaves on bristol board for display, or press them and store them in containers, such as plastic boxes. Identify each leaf and include its environment on the label. Are the collections of your classmates similar to yours? If you were to correlate the leaves to determine whether they represented the same geologic unit of time, what problem would you have? Is any overlap of vegetation apparent in leaves from the different local environments? From a literature search, can you locate the ancestors of your modern plants?

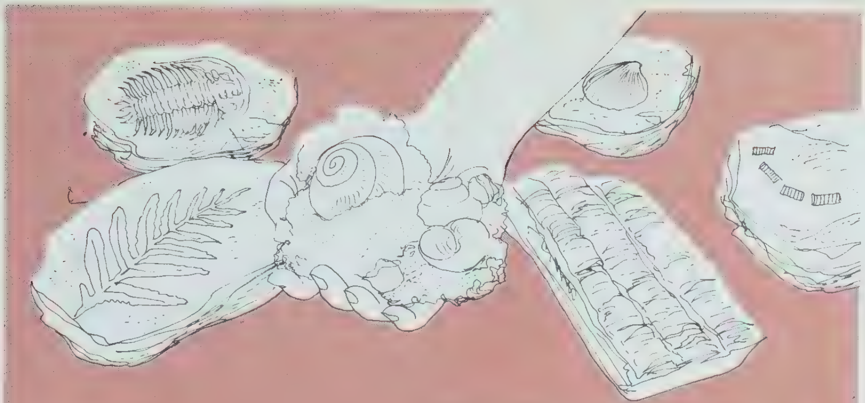


Figure 20-23.

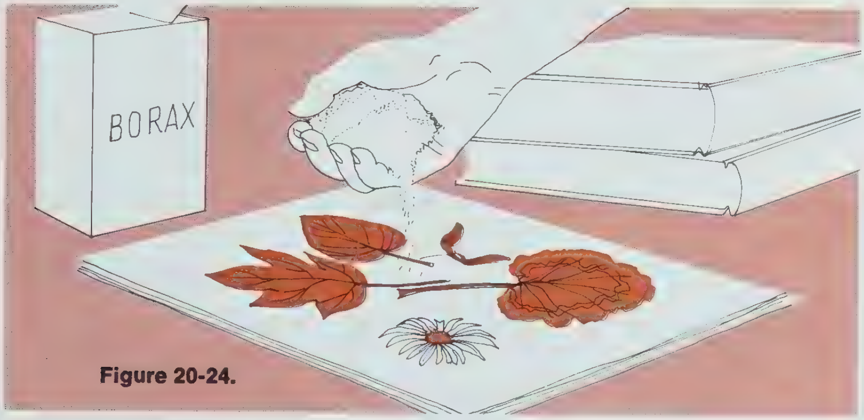


Figure 20-24.

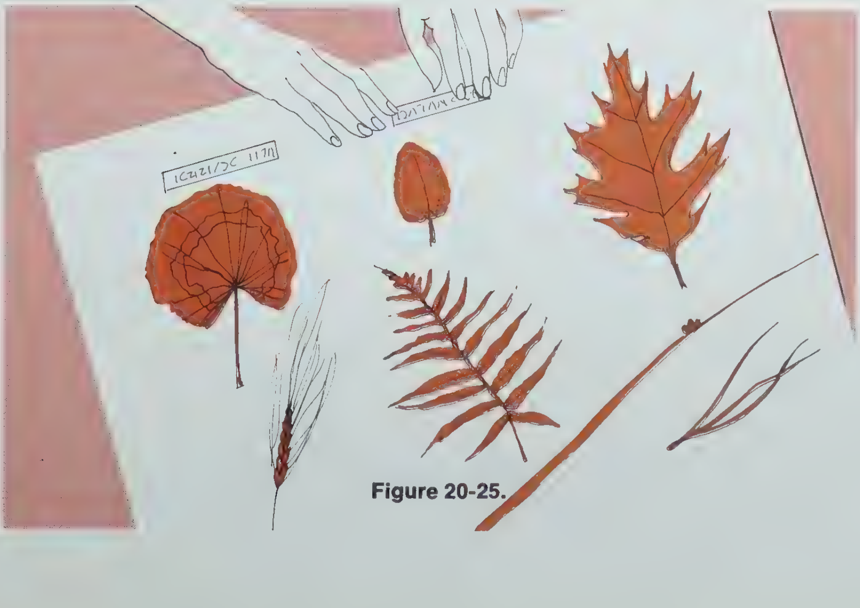


Figure 20-25.

Table 20-1. *Geologic Time Scale*

Eon	*Era*	*Period*	*Life*	*Age Estimate (Absolute)*
PHANEROZOIC	*Cenozoic*	Quaternary		Present
		Tertiary	Angiosperms dominant Mammals dominant Birds	to 60-65 million years B.P.
			Massive extinction of reptiles	
	Mesozoic	Cretaceous		60-65 million years B.P.
		Jurassic	First angiosperms Reptiles dominant Conifers and cycads	to
		Triassic	First mammals	230 million years B.P.
			Great extinction of marine invertebrates	
	Paleozoic	Permian		230 million years B.P.
		Pennsylvanian	First reptiles Lycopod trees	
		Mississippian	Amphibians dominant	
		Devonian	First amphibians Age of fish	to
		Silurian	First land plants Age of corals	
		Ordovician		
		Cambrian	Invertebrates dominant (trilobites and brachiopods)	600 million years B.P.
CRYPTOZOIC	*Precambrian Time* (Not divisible into eras or periods)			600 million years B.P.
			Primitive plants	
			Sponge spicules	to
			Primitive animals (similar to jellyfish)	4.5 billion or more years B.P.

MAIN IDEAS

1. Geologic time from earth's beginning is divided into two eons, the Cryptozoic and the Phanerozoic. Cryptozoic rocks contain little evidence of life, hence the name. Rocks of Phanerozoic time contain an increasing number of fossils.
2. Rocks of Australia contain some evidence of soft-bodied organisms that lived during Cryptozoic time. Absence of fossils does not mean a total absence of life, but instead that preservation was not possible under the conditions that existed.
3. The Phanerozoic eon lasted from 600 million years before the present to now. Phanerozoic eon is divided into three eras: Paleozoic, Mesozoic, and Cenozoic. Disappearance of old and appearance of new plant and animal groups is the basis for the division of the Phanerozoic eon into eras. Changes in fossil forms also are used to subdivide eras into periods. Changes from one era to another are usually associated with major mountain building events.
4. Fossils in Cambrian rocks include trilobites and brachiopods with phosphatic coverings.
5. Early Paleozoic fossils indicate that plants adapted to the land environment when the seas withdrew; fish then developed a simple lung and evolved into amphibians that occupied a watery environment on the continent.
6. Amphibian development into reptiles was accompanied by the development of an amniotic egg. Reptiles have been found in late Paleozoic rocks.
7. Great mountain building occurred throughout the world at the end of the Paleozoic era. The Paleozoic era ended with the disappearance of the trilobites and the extinction of many other invertebrates.
8. Developments during the Mesozoic era include appearance of angiosperms, rapid evolution of ammonites, emergence of dinosaurs as dominant animals, and appearance of flying reptiles and the first mammals and birds.
9. Crustal changes which occurred at the end of the Mesozoic era isolated Australia and South America and prevented migration of animals from one continent to another. Appearance of a land bridge between North and South America allowed northern forms to invade South America and led to the disappearance of many South American groups.

10. Evidence of early man appears during the ice age. Cro-Magnon man left excellent records of his way of life in the dry caves of France. Cro-Magnon people lived about 40,000 years ago.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

algae	fossil assemblage
ammonite	geologic revolution
amniotic egg	herbivorous
amphibian	invertebrate
angiosperm	mammal
brachiopod	marsupial
carnivorous	reptile
continental nucleus	trilobite
epoch	zone

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Apparently the first living animals were invertebrates.
2. Cryptozoic means hidden life.
3. Reptiles were the dominant life forms during the Cryptozoic eon.
4. Amphibians must spend part of their time in water.
5. Great crustal uplifts commonly are associated with the end of each era.
6. Arid conditions in the interior of continents follow uplift of high coastal mountains.
7. Cretaceous means a period of chalky limestone deposition.
8. Fish were the first animals to develop lungs.
9. Fossils of early man are numerous, complete, and widespread.
10. The Paleozoic era covers the longest span of geologic time.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. The oldest rocks that contain fossils in abundance belong to the (*Cambrian, Devonian, Permian*) period.
2. Earliest life forms are (*algae, angiosperms, invertebrates*).
3. The earliest work on the history of rocks was done by (*Adam Sedgwick, Pierre Curie, Dr. Louis Leakey*).
4. First flowering plants belong to the (*ammonites, algae, angiosperms*).
5. Female (*armadillos, marsupials, dinosaurs*) carry their young in a pouch.
6. The most useful marine index fossils of the Mesozoic era are (*ammonites, angiosperms, brachiopods*).
7. A dinosaur which fed on plants was (*tyrannosaurus, brontosaurus, armadillo*).
8. The first animal forms to develop teeth similar to those of modern mammals were members of the (*invertebrates, amphibians, reptiles*).
9. Rock of the Cryptozoic eon is predominantly (*sedimentary, metamorphic, igneous*) rock.
10. Whales are (*invertebrates, amphibians, mammals*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The eon about which least is known is the __?__ eon.
2. The era which includes the present is the __?__ era.
3. Animals without backbones are called __?__.
4. Tyrannosaurus was the largest __?__ animal of all time.
5. Two fossil invertebrates found in Cambrian rocks are __?__ and __?__.
6. Recent discoveries in Australia of impressions of jellyfish-like forms suggest that life began in the __?__ eon.
7. Dominant animal group of Cenozoic era is the __?__.
8. The earliest indication of the development of reptiles came with the discovery of a(n) __?__ egg.

9. An animal which migrated north from South America is the __?__.
10. Evidence of man first appears in the __?__ era.

D. **How and Why**

1. Why did the development of land animals come after the development of land plants? Was it by chance, or was there some reason for this sequence?
2. Why do ammonites make excellent index fossils?
3. Could dinosaurs be used as index fossils? Could they be used as facies fossils? Explain your answers.
4. Rats are among the earliest known mammals. Would they be good index fossils? Would they be good facies fossils?
5. A great reef has been discovered during drilling in west Texas. Thousands of feet of reef have been drilled through. Compare this reef with the Great Barrier Reef of Australia and indicate what the conditions in Texas must have been when the reef was forming during Permian time.
6. How could you diagram the sequence of development in the vertebrates? Remember that although one group is ancestor to a new group, the original group may continue to exist.
7. In Texas, bones of mammoths, elephants, and other animals have been found among pieces of charcoal that have been dated at approximately 29,000 years B.P. Along with the charcoal that is dated, pieces of crude flint shaped like arrowheads have been found. How do you interpret this find, and how was the date determined?
8. Bones of a mammoth were discovered along a river bank in which the evidence suggested that the rocks were about 35,000 years old. However, the bones were dated at 17,000 years. How do you account for the difference between the dating of the bones and the enclosing rocks?
9. In what way would the uplift of mountains tend to affect the climate, if uplift occurred on the west coast in the path of the westerly winds?
10. In the Pacific Ocean, the isolated Galapagos Island has developed unique types of life. How can a paleontologist use this observed phenomenon to explain the kind of life present in South America before the land bridge developed?

11. Indians and Eskimos have many similar characteristics and a resemblance to the Mongolian race of Asia. How have these similarities led to the belief that man migrated to North America from Asia?

INVESTIGATIONS

1. Report on the Cro-Magnon caves of France and caves containing traces of man in Africa. Discuss dates involved and fossils found.
2. Report on the latest findings concerning man's early history which suggest that Africa was his place of origin.
3. Discuss the authenticity of relics such as those of the Piltdown man.

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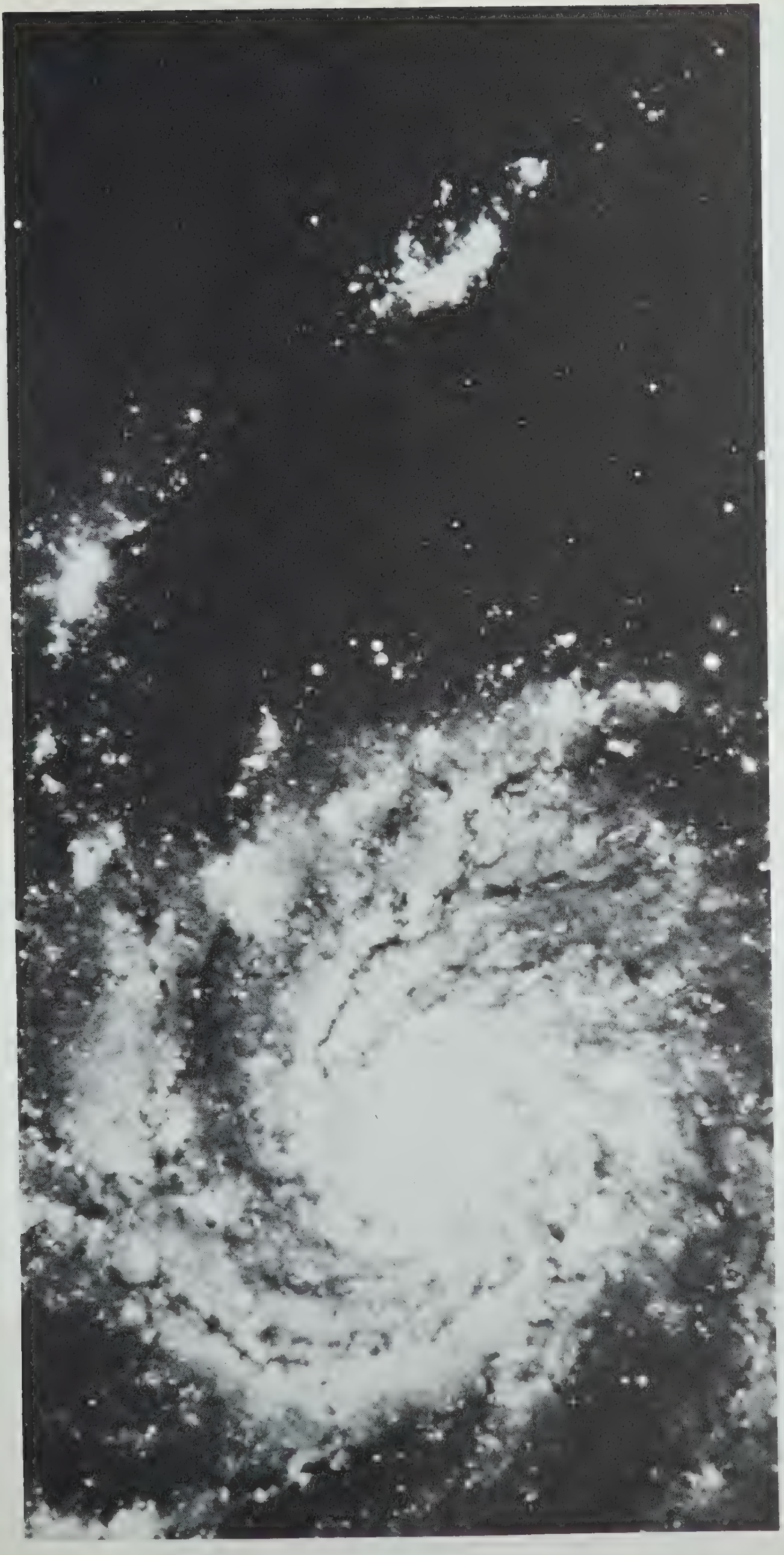
The Universe

***The UNIVERSE comprehends whatever exists; whatever can come to our knowledge by the agency of our senses. The* Stars, *the* Elements, *and this our* Globe.**

Carolus Linnaeus (1707-1778)

Knowledge of the universe in our present Space Age is not as dependent upon our senses as it was in Linnaeus' century. Optical telescopes have become larger and larger until they may have reached the limit of practical construction. Radio telescopes now furnish information beyond the bounds of the optical telescopes. Listening devices receive radio noise from distant celestial bodies. Satellites sent into space seem nearly human as they respond to commands and send back specific information on order. Unmanned and manned space vehicles venture farther and farther into the unknown.

So far, the twentieth century has seen a sudden expansion in all the sciences, with expansion in space science the most exciting. Within the coming years, moon exploration will make huge strides, and radio noise may prove to be code messages from intelligent life beyond our solar system. Life on other planets may come to be an accepted fact, and chemical evolution discovered in the laboratory may demonstrate the origin of all the celestial bodies. This is a challenging age that demands imagination, careful study, and a willingness to explore and test new ideas.



UNIT Six

The Solar System

Long before the present Space Age, men watched and wondered about the sun by day and the stars by night. Early sky watchers named and mapped the celestial bodies they could see with the unaided eye. They called the pinpoints of light which seemed to be fixed in the heavens stars. Other bodies which seemed to wander were called planets. Mapping of the heavens was based on the belief that the earth was the center around which the planets, stars, sun, and moon revolved.

21:1 *Sky Mapping*

After the invention of the telescope, more observational data was acquired that indicated that the earth is not at the center of the celestial bodies. Instead, the earth is one of a group of planets which revolve around the sun. The **solar system** includes the sun, the planets, their satellites, planetoids, comets, meteoroids, asteroids, and the interplanetary cosmic dust and gas. Better telescopes and methods of study have shown that our solar system is only a part, and not the center, of a vast multitude of stars which form a group called a *galaxy* (gal′ak see). Beyond the galaxy to which our solar system belongs, other galaxies extend into space to form the **universe.** Although all of the celestial bodies are moving, distances are so great that remote stars seem to be standing still. No wonder the word *astronomical* (as tra nahm′i kal) has come to mean numbers or distance beyond man's power to grasp or ability to calculate.

In the second century A.D., Ptolemy (tahl′a mee), a scientist in the city of Alexandria, Egypt, decided to plot or map the movement of heavenly bodies. He was particularly interested in observing the planets because they were thought to be closer to the earth than the stars. Also, the planets seemed to be moving,

Official U.S. Naval Observatory Photograph

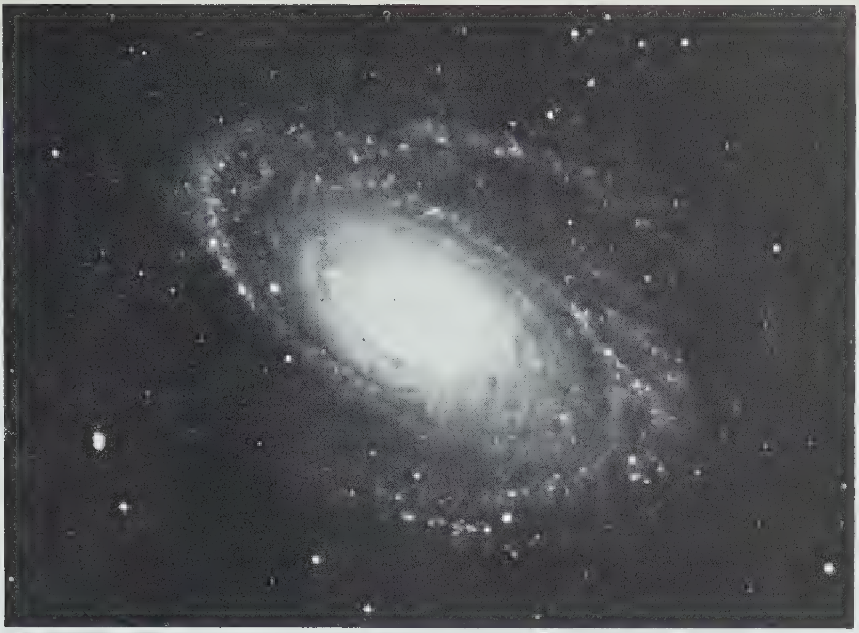


Figure 21-1. The spiral galaxy Messier 81, a vast multitude of stars, has great arms surrounding the central stellar nucleus.

but the stars appeared to stand still. To explain the movements of planets, Ptolemy worked out a mathematical model based on the idea that the earth was the center of all movement. He found that the planets appeared to move around the earth in a complex fashion. At times, some planets appeared to be moving forward; at other times, some planets seemed to move backward in the sky. In order to explain these apparent movements, Ptolemy decided that each planet revolved around a point. He reasoned that as it revolved, each planet made a series of small circles in its major orbit around the earth.

Ptolmey's idea of the universe used the earth as the center of all celestial bodies with planets revolving in small circles as they moved in their orbits around the earth.

EXPERIMENT. Roll a small wheel or ride a bicycle in a circular path. Note that the wheel makes the orbit suggested by Ptolemy. The rim of the wheel or the tire of the bicycle makes small circles as it moves in the large circle.

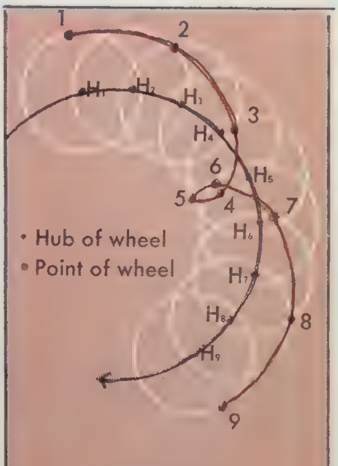


Figure 21-2.

Ptolemy required 40 circles to explain the movements that he observed. As more astronomers observed the planets and accumulated more accurate data, even more circles were required. Astronomers suggested circles within circles until the system became extremely complicated.

In 1530, Copernicus (koh per′ni kas), the Polish founder of modern astronomy, pointed out that the observed movements in the sky could be explained by a simpler system than the Ptolemaic circles. Copernicus correctly postulated that the planets of the solar system revolved around the sun. However,

he still thought that the planets moved in circles. Their true orbits were not understood until the seventeenth century when Johannes Kepler, a German astronomer, plotted their elliptical paths.

Galileo (gal a lee′oh), an Italian scientist who lived from 1564 to 1642, is most famous for his contributions to the fields of mathematics and physics. But he is also remembered for his insistence on experimentation to prove an idea. In 1609, Galileo heard about a telescope developed by Hans Lippershey, a Dutch spectacle maker. Galileo perfected his own telescope with which he studied the stars and demonstrated that planets moved around the sun rather than around the earth. Galileo published his findings to confirm what Copernicus had already suggested. Scholars of the day were not ready to accept Galileo's interpretation and his publications were suppressed. The Ptolemaic system remained the accepted explanation of the universe until the upsurge of learning occurred in the seventeenth century.

Galileo observed the skies through the earliest telescope, and found Copernicus' idea to be correct. Galileo's manuscript, which showed the sun to be the center of the solar system, was suppressed until the 17th century.

Fortunately, Galileo's manuscript was not lost and his and Copernicus' theories were read and considered by seventeenth century scientists who were willing to accept new ideas. Within the last 300 years, astronomers have finally accepted the fact that the earth is only a small member of a vast universe which is composed of almost numberless stars, some of which may have their own planets.

21:2 *Motions in the Universe*

Movement of heavenly bodies is difficult to understand because all heavenly bodies are in motion and no fixed reference point is possible.

One of man's greatest difficulties in understanding the movement of heavenly bodies is that everything is in motion. Nothing stands still to form a point of reference. If you have been on a standing train or bus that is not moving as a neighboring bus begins to move, you may have had the sensation of movement although you are at rest. If both buses are moving, your judgment of relationships becomes even more difficult. To you, the earth seems to be standing still while all other objects in space seem to be in motion. Actually, this planet is whirling through space at a great rate of speed. The illusion of being stationary makes the plotting of motions of other celestial bodies difficult.

Stars appear to be stationary because of their great distance from the earth.

When viewed from earth, stars seem to be fixed in their positions. Most stars move so slowly compared to their distance from earth, that measurement of their movement may require many years. Movement of planets, which are much closer to earth, can be recognized from one month to the next. Movement

of moons around their planets can be traced in a matter of days. Astronomers know that day-to-day observations may lead to false conclusions, but data gathered over centuries provides a basis for a more accurate interpretation of the motions of celestial bodies.

21:3 *The Celestial Sphere*

In order to plot movements of celestial bodies, astronomers have devised a **celestial sphere** which resembles a world globe. (Figure 21–3.) The movement of stars and planets as seen from earth are plotted on the sphere. Astronomers use the earth as the center of the sphere. The sky is divided into units similar to latitude and longitude on the world globe.

Stars and planets are plotted on the celestial sphere (an imaginary sphere using the earth as the center) in order to locate them in the sky.

Poles of the earth, extended outward to where they intersect the celestial sphere, are known as the **celestial poles.** All midpoints between the two poles lie on the plane of the **celestial equator.** Degrees north and south of the celestial equator are determined by planes that pass through the celestial sphere parallel to the equator much as latitude lines pass through the earth. Celestial coordinates corresponding to latitude on earth are called *declination* (dek le nae′shun). All positions north of the celestial equator are known as *plus declination*; all positions south of the celestial equator are known as *minus declination* on the celestial sphere.

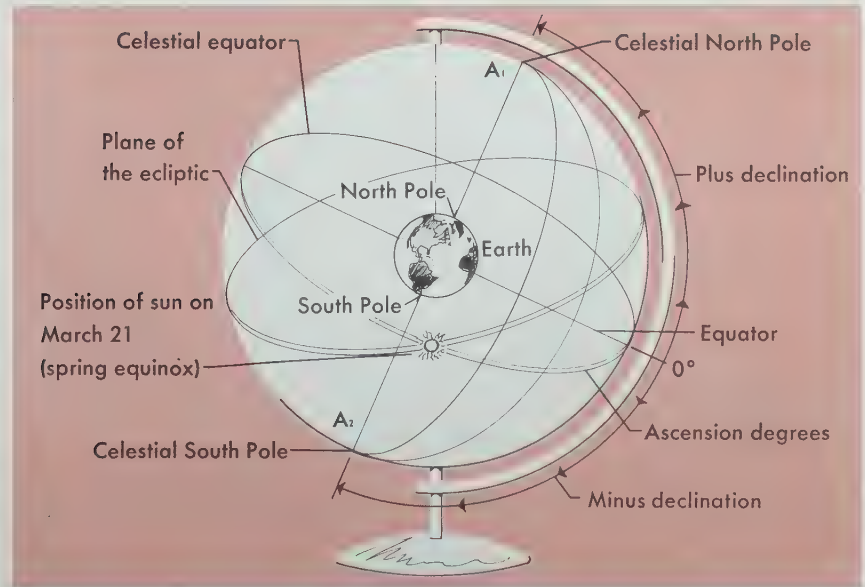


Figure 21-3. On a clear plastic sphere, stars and planetary orbits may be plotted to show the sky as it appears from earth, which is located at the center of the sphere.

On an earth globe, longitude is measured from a plane that passes through both poles and Greenwich, England. Distances are given in degrees both east and west of the longitude (0°) which passes through Greenwich. The celestial coordinate which corresponds to longitude on earth is called *right ascension*. Right ascension is measured on the celestial equator from the point where the sun crosses the celestial equator going from south to north about March 21. This point is known as the *vernal equinox* (ee′kwa nahks). Drawings of the celestial sphere show a great circle, called the **ecliptic** (i klip′tik), which represents the earth's path around the sun. Because the earth is used for the center in projecting this sphere, the sun *appears* to be moving around the earth on the path of the ecliptic. One of the two points where the two great circles (the ecliptic and the celestial equator) intersect is the vernal equinox, or zero point, from which right ascension is measured continuously in an easterly direction. This measurement is made in 24 large units, each representing one hour.

Day and night are of equal length at equinox.

Maps of the heavens illustrate star positions so that any given star may be located at any time of the year. Charts have the months indicated around the perimeter. If the chart is held

Figure 21-4. With the proper month at the bottom and with the top turned toward the north, the position of the stars overhead in the northern hemisphere will be the same as those of the chart.

in the proper position for the current month, stars may be located quickly and identified. Planets are not shown on star charts because they always appear in the same general plane and they change their position in relation to the stars. An imaginary belt about 18° wide, called the **zodiac** (zohd′ee ak), with the ecliptic in the center, contains the apparent path of the principal planets except Pluto. Positions of planets must be calculated individually using relative rate of movement of the earth and the planet.

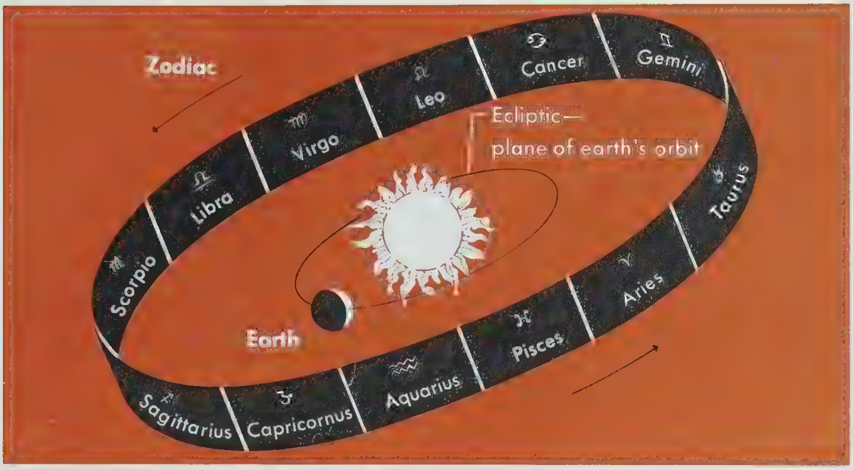


Figure 21-5. A belt called the zodiac includes the apparent paths of all planets, except Pluto.

Stars that appear to be close together as viewed from earth have been grouped into **constellations** (kahn sta lae′shuns) which, to imaginative early observers, seemed to resemble familiar objects. The Big Dipper and the Little Dipper are parts of constellations called Ursa Major and Ursa Minor (Great Bear and Little Bear). It is easier to recognize and learn the names of groups or constellations than single stars.

Constellations are groups of stars named for objects familiar to early Greek and Roman sky watchers.

21:4 *The Sun*

The solar system is known to consist of nine planets, satellites (sat′el iets) of planets, asteroids (as′te rawids), meteoroids (meet′ee a rawids), and comets, all revolving around the sun, a hot star. Because of its great mass of 2.2×10^{27} tons, the sun holds members of the solar system in orbit by its gravitational attraction. Although composed mainly of hydrogen and helium, the two lightest elements, the sun accounts for 99.86 percent of the solar system's mass.

Planets of the solar system rotate on their axes and revolve around the sun at various rates.

Average rotation period for the sun is 27 days.

Traces of most elements found on earth are also present in the sun. The average density of the sun is only 1.41 g/cm^3 compared to 5.5 g/cm^3 for the earth, although the diameter of the sun is approximately 864,600 mi. The sun has a rotation rate of 25 days at its equator, 34 to 35 days near its poles. Gases at sun's equator move more rapidly than gases at the poles; consequently, rotation rate is not the same for both positions.

Transmutation (trans meu tae′shun) or changing of hydrogen gas into helium gas is the source of the sun's energy. These nuclear changes are similar to those that occur within the explosion of a hydrogen bomb. The process of transmutation is called hydrogen "burning"; the product helium is known as "ash." Temperatures of approximately 15,000,000°C in the sun's interior cause particles to move at tremendous speeds. Protons which normally would repel one another are forced to combine. The resulting combinations usually are unstable. But if the combined protons are joined by other particles, a stable helium nucleus of 2 protons and 2 neutrons may be formed. Mass which is converted to energy during transmutation becomes the source of the sun's heat energy and light energy. The process of transmutation in the sun will continue until most of the sun's hydrogen has been changed to helium.

Radiant energy originates in the sun.

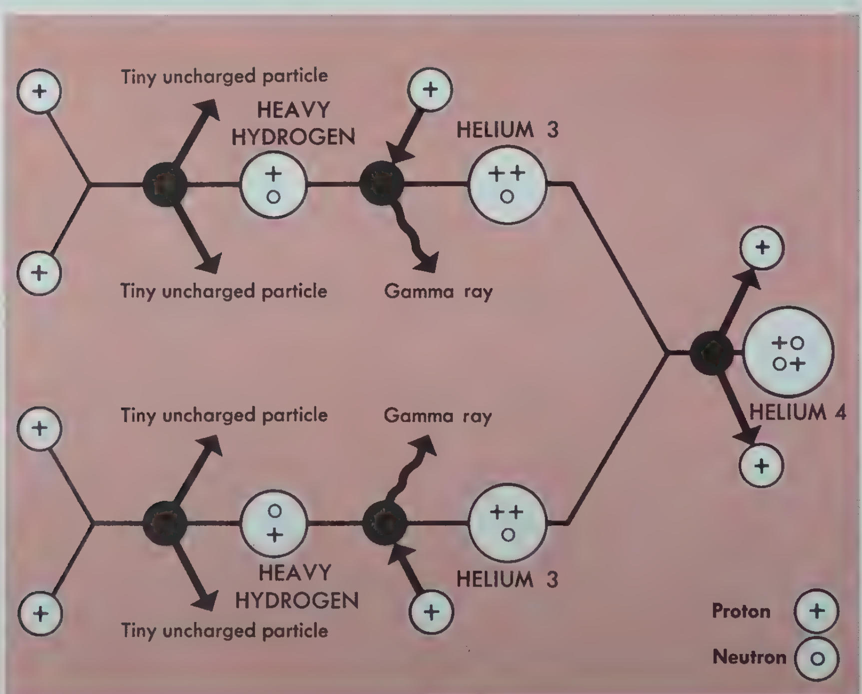


Figure 21-6. High temperatures in the sun cause protons to unite with such velocity that they combine in a sequence of reactions to form helium.

High Altitude Observatory

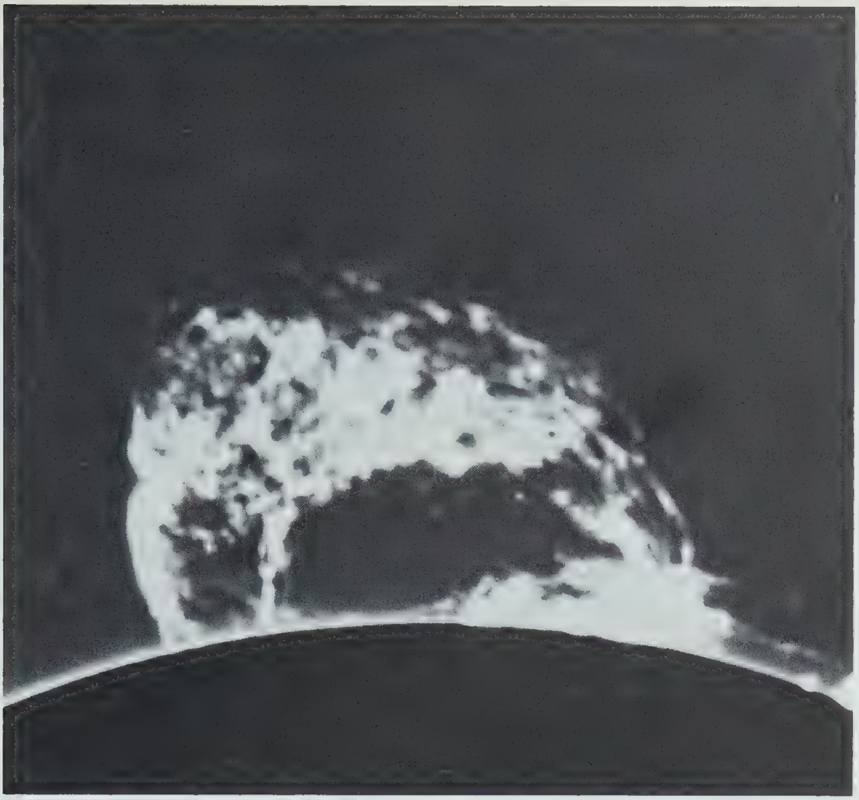


Figure 21-7. Activity of solar flares, protons and electrons streaming outward from the sun, affect radio reception on earth.

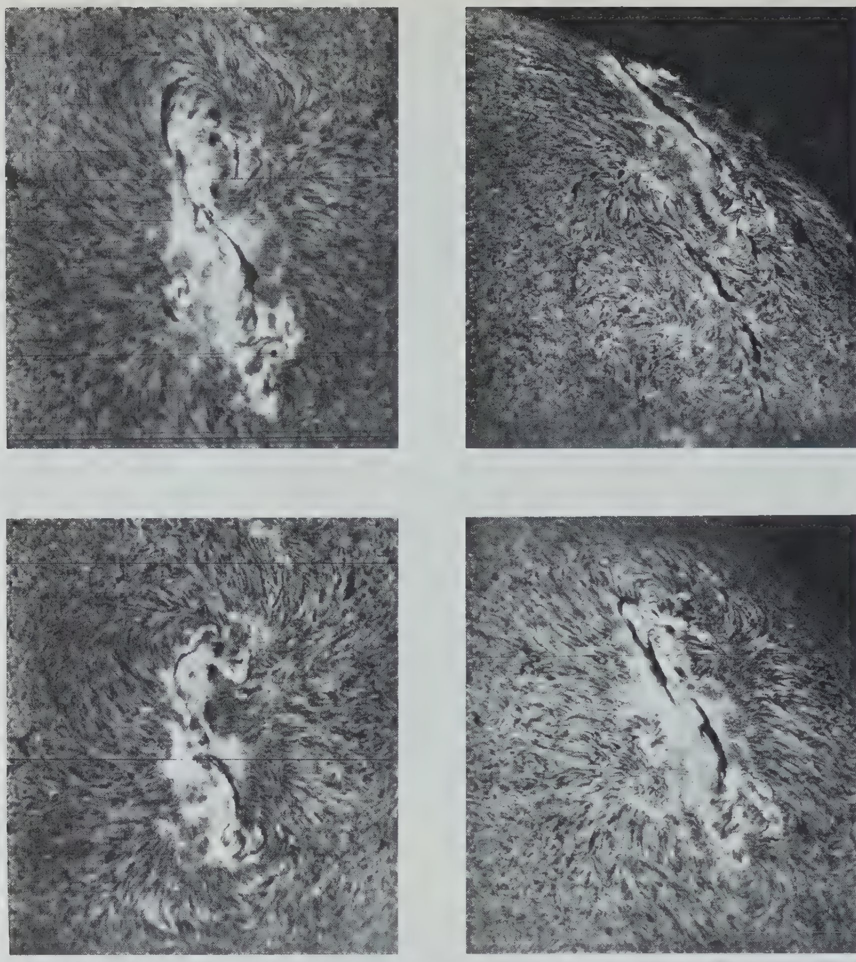
Within the sun's interior, pressures exist as a result of the transmutation of hydrogen and the high temperature of the sun's gases. These internal pressures are counterbalanced by the weight of overlying gases. As radiation is produced, it passes outward from the sun's interior to the surface where it escapes into space. In this way, equilibrium is maintained.

The sun's surface contains the visible photosphere, a transparent layer of gas called the chromosphere, and the corona, an outer layer of widely separated protons and electrons.

The **photosphere** (foht′a sfir) is the surface of the sun which we see. This layer gives off visible radiation. Lying outside the photosphere is the chromosphere (kroh′ma sfir), a layer of hot gas which can be seen during an eclipse or with the aid of an artificial masking device in a telescope which blots out the brilliant photosphere. Seen through a telescope the chromosphere is a brilliant red halo extending about 6,000 mi beyond the photosphere. From the chromosphere, *prominences* of gas shoot outward sometimes for millions of miles. Some of them fall back toward the sun; some may be propelled outward into space.

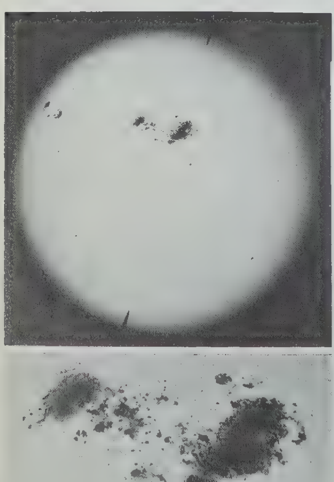
Beyond the chromosphere is a still thinner and more transparent zone, called the **corona** (ka roh′na). This filmy envelope of highly ionized gas can be observed only during a total eclipse of the sun.

Figure 21-8. The surface of the sun is constantly changing as interior gases break through the surface and escape.



Mount Wilson and Palomar Observatories

Figure 21-9. Sunspots, the dark areas of the photosphere where temperatures are lower than the surrounding gases, expand as they move across the sun.



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Sunspots first appear on the photosphere as small areas, less brilliant than the photosphere, although their diameters may be over 1,000 mi. Temperatures are about 4,000°C (7,200°F) compared to 5,480°C (9,900°F) for the surrounding materials. Within a few days, sunspots may expand to several thousand mi in diameter. One of the largest sunspot areas ever observed appeared from February 5 to May 11, 1947. It covered approximately 7 billion square miles of the photosphere. Sunspots may last a day or as long as several months. Sunspot activity seems to occur in cycles of about 11 years. The longest observed period was 17 years; the shortest was a little over 7 years.

Solar flares are sudden increases in brightness of areas near sunspot groups. Protons and electrons stream outward at a velocity ranging from 200 mi/sec to 500 mi/sec. Many of the protons and electrons reach the earth and some of them may travel to the limits of the solar system. While flares are active, they cause disturbances in radio reception and affect the earth's magnetic field.

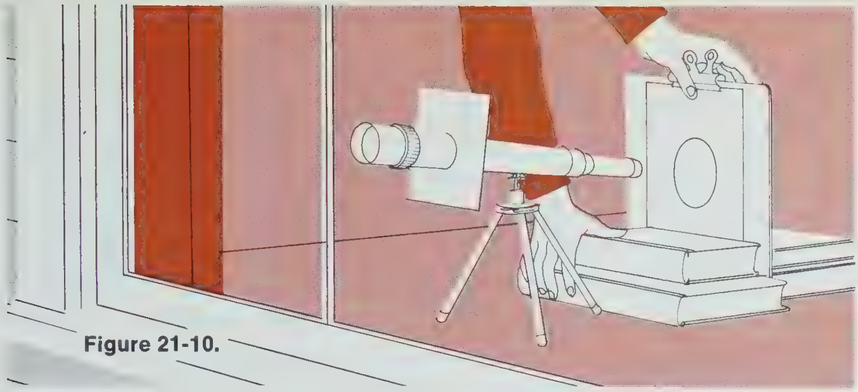


Figure 21-10.

EXPERIMENT. Caution: Never look directly at the sun with unprotected eyes or through a telescope or binoculars unless they have special lenses. *Ordinary sun glasses or photographic negatives are not sufficient protection against the sun's rays. The best way to examine the sun is by looking at its image on a sheet of white paper. Make your observations at sunrise or sunset when the earth's atmosphere filters some of the dangerous rays. Never look at the morning sun after it changes from red to orange, or at the evening sun before it changes to red.*

Put a telescope on a tripod or stand it in a window facing the sun. Prop a clipboard holding a sheet of white drawing paper opposite the eyepiece of the telescope. Arrange a sun shield (a square of heavy cardboard) on the telescope as illustrated in Figure 21–10. Move the clipboard back and forth until the largest possible image of the sun appears on the board. Focus the lens so that the image is distinct. Trace the outline of the sun's image and include any sunspots. Sometimes there are no sunspots, but usually several are present and they can be observed as they move across the sun.

Keep the telescope in position so you can make observations on succeeding days. Repeat the examination of the sun's image each day and draw the image and any sunspots on a new piece of paper each day. Compare the location of the spots from day to day for at least one week. Do the sunspots have the same shape each day?

Planets, their moons, meteoroids, comets, and a belt of asteroids move around the sun. (Figure 1–8.) All are members of the solar system with motions determined by their position relative to the sun. (Table 21–1.) Astronomers have established that planets rotate on their axes as they move around the sun and that all of their axes appear to be tilted at some angle to the sun's equator. As the planets revolve around the sun, most of them orbit in nearly the same plane as the earth.

21:5 Mercury

Mercury, the smallest planet of the solar system, is closest to the sun. Its day is equal to 58.6 earth days, but its year is only 88 days long.

Mercury is the smallest planet of the solar system. It orbits closest to the sun at an average distance of 36,000,000 mi. Because of its small size, dark appearance, and nearness to the sun, telescopic observation and photography of Mercury are quite difficult. In 1889, observational difficulties led astronomers to conclude that Mercury had a rate of rotation equal in length to its year of 88 earth days, and that one side always faces the sun. Radar measurements in 1965 proved beyond doubt that Mercury rotates once during ⅔ of the time required for its revolution around the sun. Therefore, Mercury's period of rotation is equal to 58.65 earth days. This results in the same side of Mercury facing the sun every second revolution at perihelion, the orbital position nearest the sun. (Section 1:4.) Similarly, the opposite side of the planet faces the sun at perihelion every other revolution.

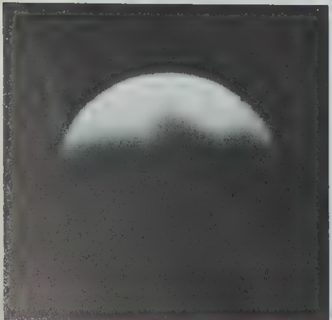
The side of Mercury turned away from the sun is cold; the sunny side is hot. Because there is little or no atmosphere, the solar heat is not distributed over the planetary surface by convection as it is on earth. When Mercury is at its mean distance from the sun, its temperature is about 340°C (650°F). Mercury is so small that its surface gravity is only ⅜ that of the planet earth.

21:6 Venus

Venus, the second planet outward from the sun in the solar system, is at a mean distance of 67,200,000 mi from the sun. Venus, earth's nearest planetary neighbor, approaches earth within 26,000,000 mi.

Earth and Venus are often called twin planets because of their similar characteristics. A feature common to both Venus and earth is the presence of an atmosphere. Many attempts have been made to determine the composition and temperature of Venus' atmosphere and the character of its surface. However, the atmosphere is so dense and cloudy that telescopic observation of Venus' surface from the earth is impossible. Although every known observational method of investigation has been used, many questions concerning Venus' atmosphere and surface remain unanswered.

Figure 21-11. Venus, earth's twin planet, as seen through the telescope at Mount Wilson.



Mount Wilson and Palomar Observatories

Surface temperatures on Venus have been difficult to determine because of the cloud cover. A Russian probe which made a soft landing reported temperatures ranging from approximately 45°C (114°F) to 280°C (536°F). The higher tempera-

ture probably represents the surface of Venus; the lower temperature readings probably are from the atmosphere above Venus.

Venus rotates clockwise, or *retrograde*, compared to the counterclockwise rotation of the other planets. Radar echoes from an identifiable reflecting "feature" on the surface of Venus were tracked from day to day. Thus, it was possible to determine that the period of rotation is approximately 243 days. Measurements are repeated every 19 months when Venus passes between the earth and the sun and all three bodies are in an alignment.

Venus' day is equal to 243 earth days. Its year is equal to 224 earth days.

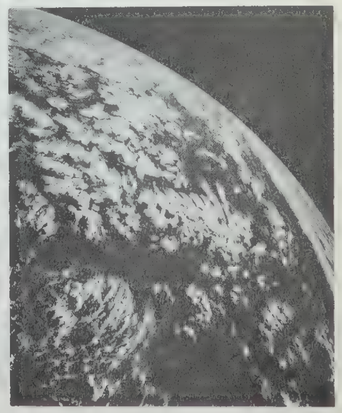
Although Venus and earth are similar in many respects, some important differences have been determined. Russian probes report that no magnetic field or radiation belt is present. American flybys suggest an extremely weak magnetic field.

Present evidence indicates that Venus' atmosphere is predominantly carbon dioxide. Estimates range from 72 percent to 98 percent carbon dioxide. No oxygen has been found, and perhaps nitrogen is absent also. Lack of oxygen and the high temperatures of Venus make earth-like life an impossibility for earth's twin planet. Atmospheric pressure estimates range from 7 to 15 times earth's pressure. These pressure estimates are much lower than early theories suggested. However, Venus atmosphere is so dense that light from the sun is refracted away from Venus' surface.

21:7 *Earth*

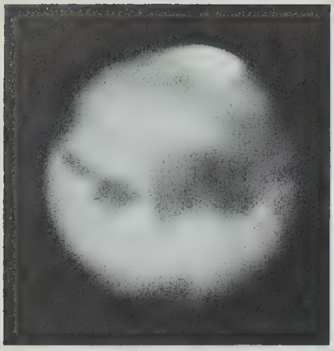
Earth, the third planet outward from the sun, is at a mean distance of 93,000,000 mi from the sun. Earth differs from other members of the solar system because its atmosphere contains oxygen, and its temperature range of about 85°C (185°F) allows water to exist in gaseous, liquid, and solid states. Like the sun, stars in other galaxies may have planets with conditions similar to conditions on earth. But within our solar system, earth may be the only planet where life exists.

Figure 21-12. This view of earth from space shows the Indian Ocean off the coast of Australia.



NASA

Earth rotates on its axis once in approximately 24 hours and revolves around the sun once in approximately 365 days. These repeated motions are the basis for our measurement of time. Earth's one natural satellite, or moon, revolves around the earth in 27⅓ days. (Section 1:4.) Density of the earth is 5.5 g/cm^3. Possibly some of earth's original gases have been lost. But other gases have formed during the solidification of igneous rock, and most of these gases have been retained to form earth's unique atmosphere.



Mount Wilson and Palomar Observatories

Figure 21-13. Mars observed through the telescope at Mount Wilson.

21:8 *Mars*

Mars' color, brightness, and nearness to earth have attracted the attention of astronomers for many centuries. The orange to reddish color of Mars is easily recognizable with the unaided eye. As early as 1610, Galileo observed Mars through the first astronomical telescope.

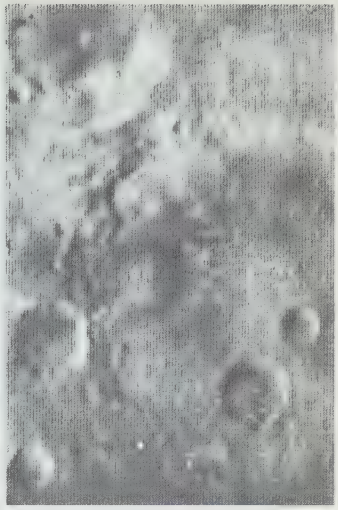
Mars orbits the sun at an average distance of 142,000,000 mi. Its orbit departs from a true circle more than any other planet except Mercury and Pluto. In 1666, the Italian astronomer Cassini determined the rotational period of Mars with less than a 3 minute error. Today, the accepted rotational period for Mars is 24 hours, 37 minutes, and 22.6 seconds. Mars revolves around the sun in approximately 687 earth day.

White patches near Mars' poles of rotation became known as polar caps because of their apparent similarity to earth's polar ice caps. Ice, snow, frost, or frozen carbon dioxide have been suggested as the polar cap material. The white patches expand at one pole and shrink at the other pole simultaneously, suggesting a relationship to changing seasons.

In 1877, the Italian astronomer Schiaparelli (skahp a rel′ ee) interpreted large light and dark areas as land and sea, respectively. He also named many straight line markings *canali* which means channels. Others translated this word as canals. Based on the supposed presence of canals, many people came to believe that Mars supported intelligent life. Recent photos of Mars' surface have supplied no further evidence of the existence of a true canal system.

Schiaparelli's idea of Martian canals influenced Percival Lowell of Boston, Massachusetts. In 1894, Lowell founded the Lowell Observatory at Flagstaff, Arizona. For many years, Lowell studied there and mapped Mars. He believed that meltwater from the polar caps was distributed through a vast irrigation system built by intelligent life to support vegetation on Mars. Although Lowell's theories concerning Mars were not well accepted, he is noted for predicting the existence of a ninth planet. Such a planet, called Pluto, was discovered in 1930, 14 years after Lowell's death.

In spite of all the attention given to Mars, the question of the presence of life persists. Biologists and chemists have found no positive evidence that Mars cannot support life which is chemically similar to life on earth. But if life is present on Mars, it need not resemble life on earth. Martian life forms might consist of microorganisms, microbes, or even molds or mosses. Or



NASA

Figure 21-14. The surface of Mars between Mare Sirenum and Mars Cimmerium, showing Atlantis.

life might be completely different from any forms on earth. Experiments with earth soil organisms under artificial weather conditions similar to those of Mars have proved that microorganisms would be more likely to survive than larger organisms. Microorganisms are more resistant to freezing and thawing than large organisms. Because of the low temperatures on Mars, ice crystals would tend to form in the cells of large organisms.

Measured surface temperatures of Mars have a wide range. At the south polar cap, temperatures go down to about —100°C (—150°F) during the winter. An average range from —70°C to + 31°C (—100°F to +80°F) is comparable to ranges of temperature on earth. However, the daily temperature range on Mars may reach 80°C (180°F) in some areas. This range compares most unfavorably with earth where the maximum daily range is approximately 10°C (50°F). Some areas of Mars might be favorably located with respect to climate, and the presence of life cannot be ruled out on the basis of temperature.

Because of the masking effect of earth's atmosphere, various analyses of Mars' atmosphere have given conflicting results. Measurements from a high-altitude, unmanned balloon indicated the presence of water vapor and carbon dioxide in Mars' atmosphere. Evidence obtained during an unmanned spacecraft flyby indicated that Mars' atmosphere consists primarily of carbon dioxide. Atmospheric temperature was found to be about —90°C (—130°F). Surface atmospheric pressure was determined to be less than 0.75 percent of the pressure at the earth's surface.

Data indicate that Mars has neither a magnetic field nor radiation belts of any significance. If a magnetic field is absent, charged particles are not trapped and the planet is exposed to bombardment by cosmic rays and to the solar wind. Ultraviolet radiation from the sun would not be absorbed or filtered by the thin Martian atmosphere. The presence of harmful cosmic and solar radiation reduces the chance for the survival of even simple organisms, such as bacteria, spores, or fungi.

More than 70 craters have been discovered within less than one percent of Mars' photographed surface. Their size and distribution resemble craters on the highlands of earth's moon. The presence of craters supported the theory that the surface had been struck by meteorites, had melted, cooled, and cracked along lines that joined the impact craters. Several astronomers believe the so-called canals are these crustal faults.

Mars' surface contains many impact craters and straight line markings which may be faults.

Phobos and Deimos are satellites of Mars which were predicted by Jonathan Swift but not discovered until 150 years later.

Mars' two moons were discovered in 1877 by Hall, an American astronomer. He named the Martian moons Phobos (foh' bohs), meaning fear, and Deimos (dee'mohs), meaning panic, after the horses that pulled the chariot of Mars, the mythical Roman god of war. Phobos, the larger moon, is unique among the satellites of the solar system. It is the only satellite that revolves around its primary (Mars) in less time than the rotation period of its primary.

Although Hall did not discover the Martian satellites until 1877, Jonathan Swift mentioned such satellites 151 years earlier in his book called *Travels into Several Remote Nations of the World by Captain Lemuel Gulliver*, commonly known as *Gulliver's Travels.*

> "They [the astronomers of Laputa] have likewise discovered two lesser stars, or satellites, which revolve about Mars, whereof the innermost is distant from the center of the primary planet exactly three of the diameters, and the outermost five; the former revolves in the space of ten hours, and the latter in twenty-one and an half; so that the squares of their periodical times are very near to the same proportion with the cubes of their distance from the center of Mars, which evidently shows them to be governed by the same law of gravitation, that influences the other heavenly bodies."*

Swift's nearly accurate statement in 1726 of the periods of revolution for Phobos and Deimos is startling! Had Swift used ancient writings now lost that contained an advanced knowledge of astronomy? The source of his knowledge of the two moons of Mars remains one of the major mysteries of science and literature.

21:9 *Asteroids*

Asteroids are fragments of cosmic matter which orbit the sun between Mars and Jupiter.

Beyond the planet Mars, moves a belt of asteroids. **Asteroids** are fragments that orbit the sun in a position generally between Mars and Jupiter. Material in the asteroid belt is similar to matter in other planets but in this region fragments may not have united. Probably no one fragment or mass was large enough to dominate the belt and collect other fragments. Perhaps the fragments are the remains of a planetary catastrophe that may have occurred millions of years ago.

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* Jonathan Swift, *Gulliver's Travels* (New York, The Modern Library, 1931), p. 193.

Figure 21-15. Four of the largest asteroids are drawn to the same scale as a portion of the moon's surface.

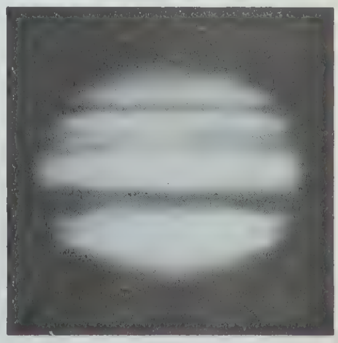
Thousands of asteroids are present in the asteroid belt. Their size ranges from particles of dust to fragments 480 mi in diameter. The largest asteroid is named Ceres. Most asteroids are too small to be observed through a telescope, but they appear in photographic series in which movement can be detected. Some asteroids have been pulled into the gravitational field of the planet Jupiter, which lies beyond them in the solar system. These asteroids, known as the Trojan asteroids, either follow or precede Jupiter in its orbit around the sun. Astronomers believe that, from time to time, Jupiter may cause other asteroids to change their orbital paths. Some fragments are sent flying toward the sun; others are forced outward toward more distant planets. A few asteroids follow eccentric paths that bring them close to earth. Icarus was calculated to pass within 4,000,000 mi of earth in 1968; Geographos was calculated to pass within 6,000,000 mi of earth in 1969.

Most asteroids cannot be observed in a telescope but can be photographed.

21:10 *The Distant Planets*

Jupiter orbits at a mean distance of 484,000,000 mi from the sun. It is a massive planet with a volume 1,300 times that of the earth and a density only one-fourth that of earth. Jupiter has an atmosphere hundreds of miles deep which consists of hydrogen, ammonia (NH_3), and methane (CH_4) gases. The planet Jupiter's surface gravity is about 2.5 times as strong as that of the earth because of Jupiter's tremendous mass. Although Jupiter consists largely of gas, it may have substantial portions that are liquid or even solid, due to the tremendous pressures which are thought to be present. Jupiter rotates on its axis once every 9 hr 50 min and orbits the sun once in 11.9 years. Like earth, Jupiter is surrounded by radiation belts. Jupiter's belts emit powerful radio waves that reach the earth.

Figure 21-16. Massive Jupiter has an atmosphere hundreds of miles deep.



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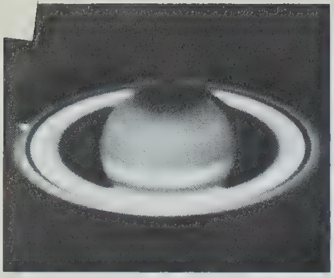

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Figure 21-17. Saturn's unique rings can be seen clearly through the telescope.

Jupiter has 12 known moons, the largest number of natural satellites of any planet. Four of Jupiter's satellites were discovered by Galileo in 1610.

Saturn moves beyond Jupiter at a mean distance of 889 million mi from the sun. Saturn is 95 times as massive as the earth, but its density is only 0.127 that of earth. Saturn requires about 29½ earth years for its orbit around the sun. Rotation on its axis requires 10 hours and 14 minutes. Saturn is unique in that it is surrounded by 3 rings of material that appear to consist of snow and cosmic grit. The diameter of the ring system is 171,000 mi, yet the rings are only 10 mi to 20 mi thick. According to some scientists, the *cosmic grit* is material which was not gathered up by Saturn during formation of the planet. Other scientists think that it is the remains of moons torn apart by Saturn's tidal action. Saturn's surface is obscured by clouds. It has 10 moons; its largest satellite, called Titan, is as big as Mercury and has an atmosphere of methane gas. This is the only satellite of a planet known to have its own atmosphere.

Uranus is another massive gaseous planet, which consists principally of hydrogen, methane, and ammonia gases. Its mass is 14½ times that of earth, and its diameter is nearly 4 times greater. Uranus moves beyond Saturn at a mean distance of 1,784,000,000 mi from the sun. It has 5 natural satellites. Uranus is barely visible to the unaided eye and was first observed with the aid of a telescope in 1781. Uranus revolves around the sun once every 84 earth years and rotates on its axis once every 10 hours and 49 minutes. Its axis of rotation lies in its orbital plane which is unique among the planets. Therefore, with the completion of a half-revolution, alternate poles of Uranus point toward the sun.

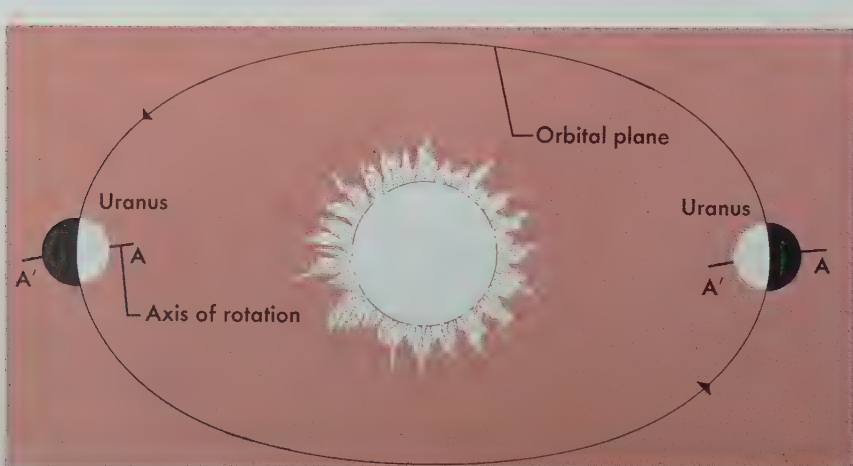

Figure 21-18. Uranus' axis of rotation is almost parallel to its orbital plane, causing alternate poles (A, A′) to point toward the sun every half revolution.

During their study of Uranus, astronomers observed that its orbit has certain irregularities that suggested the gravitational attraction of another body. Their search for another planet led to the discovery of Neptune beyond Uranus. Neptune is at a mean distance of 2,800,000,000 mi from the sun. Its orbit of the sun requires 165 years. Neptune is not visible to the unaided eye, but, seen through a telescope, it appears to have a pale green color. Its atmosphere probably is similar to that of Uranus. Like Saturn and Uranus, Neptune is a gaseous planet. Its diameter is 28,000 mi, but its density is only 0.4 times that of the earth. Neptune has 2 natural satellites.

Pluto was discovered in 1930 and appears to be the most distant planet in our solar system. Because Pluto is so far away, it reflects less light than planets closer to the sun. Although its measurements are uncertain, its diameter has been estimated to be approximately 3,600 mi. Pluto's orbit is the most eccentric of all the planets and ranges from 2,700,000,000 mi at perihelion to 4,600,000,000 mi at aphelion. During its 248-year orbit around the sun, Pluto passes within Neptune's plane of orbit. In spite of intensive study of the sky beyond Pluto, no planets have been discovered.

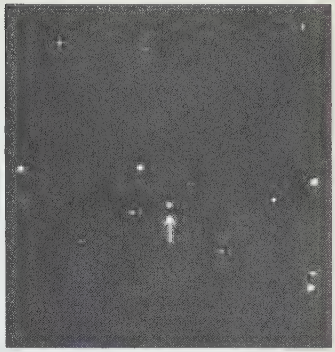

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Figure 21-19. Pluto, the smallest and most distant planet, is difficult to see even with the most powerful telescopes.

Pluto is a small planet whose orbit may represent the outer limit of the sun's gravitational field.

21:11 *Comets, Meteoroids, Meteors, and Meteorites*

In addition to the planets and their satellites, the solar system includes comets and meteoroids. Comets are not satellites of any planet. Instead, **comets** are independent accumulations

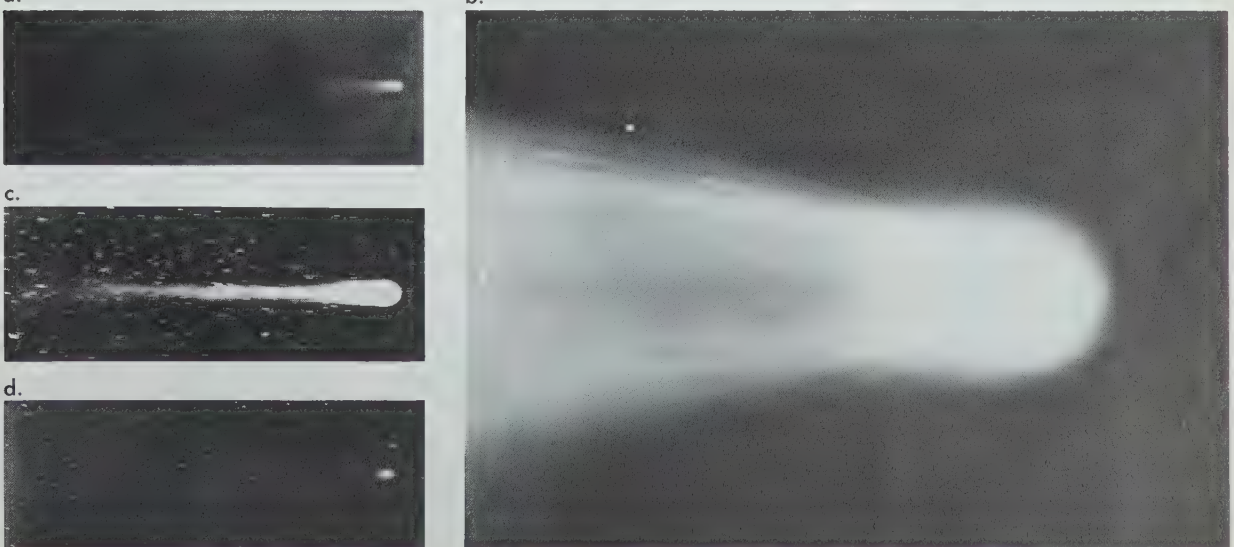
Figure 21-20. Halley's comet, observed since 240 B.C., last appeared in 1910. On April 26 (a.) the comet was barely visible; on May 8 (b.) its approach to the sun was accompanied by vaporization of its head and the formation of a tail millions of miles long. As the comet moved away from the sun by May 28 (c.), the tail began to dissipate; on June 11 (d.) the comet was barely visible.

a.

b.

c.

d.



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Comets orbit within the solar system, but they are independent of the planets and have various orbital paths.

of cosmic grit and ice which may or may not orbit in the same plane as the planets. Comets follow elliptical orbits which some astronomers believe may range 10 trillion miles (1.5 light years) from the sun. Some comets follow paths that bring them close to the sun, at which time they may be broken into small pieces. Comets become most spectacular as they approach the sun. The nucleus consists of masses of frozen methane, ammonia, and water as well as meteoritic particles. As a comet approaches the sun solid portions of the nucleus are sometimes vaporized. The resulting gases are emitted explosively and trail behind the head for millions of miles. This trail always points away from the sun. The comet's mass is in the nucleus. The head of the comet includes the nucleus and coma, a foggy envelope surrounding the nucleus.

Meteoroids consist of fragments formed during the disintegration of either comets or asteroids. Some meteoroids remain in space and others rain down on the sun and planets. During the approximately 4.5 billion years of the earth's existence, scientists estimate that this accumulation of cosmic dust, if distributed evenly around the earth, would form a layer 10 ft deep. Approximately 2 million tons of "star dust" are added to the earth every year. (Section 11:5.) Compared to the 6.6 trillion ton mass of the earth, the amount of meteoritic material is insignificant. But as a clue to matter in space, "star dust" is indeed significant.

Figure 21-21. In September, 1966, this giant meteor streaked across the sky in the eastern half of the nation and trailed flames described as a combination of red, orange, green, and blue.

Photo by James C. Fish

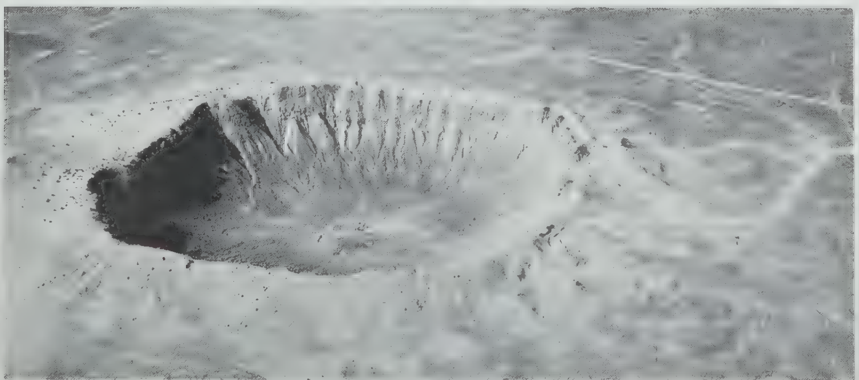
Meteoroids are too small to be observed in space, but they may be photographed or be detected by radar as they approach earth's atmosphere. **Meteors** are meteoroids that reach our atmosphere; **meteorites** are meteors that reach the earth's surface. Scientists believe that meteors and meteorites are similar to the cosmic materials from which the planets were formed. Most meteors burn up as they pass through the atmosphere before they reach the earth's surface. Those that reach the earth are valuable sources of information about the universe beyond the earth.

Meteorites are classified according to their composition. **Siderites** (sid′a riets) are meteorites composed of iron, or iron and nickel combinations. These are the largest known meteorites and may represent approximately the same composition as the earth's core. **Aerolites** (ar′a liets), or stony meteorites, are smaller and more difficult to identify than the siderites. Because these stony meteorites are similar to materials found on the earth's surface, probably many more fall to earth than are

recognized as coming from space. Stony meteorites usually contain some iron particles and consist mostly of iron-magnesium silicates. They appear to be somewhat like volcanic rocks. **Siderolites** (sid′e ra liets) are the rarest meteorites. They resemble a sponge, but are made of iron. Between the iron particles, spaces are filled with minerals similar to the stony meteorites. Siderolites are intermediate in composition between stony and iron meteorites. They contain both iron-nickel and iron-magnesium silicates.

Meteorites are rarely found—only 1,500 have been recovered. Undoubtedly, many more have fallen but have not been recognized. Because of heating as they pass through earth's atmosphere, meteorites are black when they reach the earth's surface. But weathering of the iron changes them to rusty brown. Surface crusts on stony meteorites resemble space capsules that have been burned or fused as they returned to earth. Meteoroids may strike and plunge through earth's atmosphere with velocities as high as 45 mi/sec. The impact velocity depends on the relative orbital speeds and directions of motions of the two bodies. Great craters in the earth's surface have been formed by the impact of meteorites. In 1908, an impact in Siberia created such an explosive force that a forest was flattened and damage extended over a radius of 100 mi. Meteor Crater, Arizona, is another great depression in the earth attributed to the impact of a meteorite. Probably many such craters have been formed during the earth's existence. The surface of Mars and of the moon suggest how earth's surface may have appeared before earth's atmosphere contained water, and before weathering and erosion erased the marks of impact. Some craters formed early in the history of the earth may have been covered by later deposits.

Exceptionally large meteorites may form craters like those on Mars and the moon.



Official U.S. Air Force Photo

Figure 21-22. Meteor Crater at Winslow, Arizona, is estimated to have been formed 20,000 to 75,000 years ago. Millions of tons of pulverized sandstone as well as 15 to 20 tons of meteoritic iron-nickel fragments represent the impact effects of a large mass meeting the earth at meteoritic velocities.

PROBLEM

Diagrams of the distance relationships between members of the solar system cannot be drawn to scale because of the great distances involved. However, a diagram can give you an idea of their respective positions. Using the scale ⅛ in = 2,000 mi, calculate the size of the paper needed to draw a scale diagram of the sun, the earth, and the moon. Round off the figures to the nearest whole number. Use the following approximations for the computations.

Earth's diameter	8,000 mi
Sun's diameter	865,000 mi
Moon's diameter	2,000 mi
Distance from earth to sun	93,000,000 mi
Distance from earth to moon	240,000 mi

Using the same scale and Table 21–1, calculate the length of the paper needed to diagram the approximate distances to the other planets.

Table 21-1. ***The Planets***

PLANET	*Satellites*	*Mean Distance from Sun*	*Length of Year*	*Sidereal Rotation*	*Diameter at Equator*	*Relative Volume (earth = 1)*	*Relative Mass (earth = 1)*	*Mean Density (water = 1)*
MERCURY	0	35,983,000 mi	87.969^{d}*	$58^{d}\ 39^{m}$	3,100 mi	0.06	0.0543	5.2
VENUS	0	67,235,000 mi	224.70^{d}	$243^{d}\ 9^{m}\ 36^{s}$	7,550 mi	0.86	0.81485	5.1
EARTH	1	92,956,000 mi	365.24^{d}	$23^{h}\ 56^{m}\ 4.1^{s}$	7,927 mi	1.00	1.00	5.52
MARS	2	141,637,000 mi	686.98^{d}	$23^{h}\ 37^{m}\ 22.67^{s}$	4,220 mi	0.15	0.1069	4.0
ASTEROIDS**								
JUPITER	12	484,000,000 mi	11.86^{y}	$9^{h}\ 50^{m}\ 30^{s}$	88,700 mi	1,317.00	317.8	1.34
SATURN	10 and 3 rings	887,100,000 mi	29.46^{y}	$10^{h}\ 14^{m}$	75,000 mi 171,000 mi***	762.00	95.22	0.68
URANUS	5	1,784,000,000 mi	84.02^{y}	$10^{h}\ 49^{m}$	29,000 mi	50.00	14.54	1.6
NEPTUNE	2	2,797,000,000 mi	164.8^{y}	$15^{h}\ 48^{m}$	28,000 mi	42.00	17.23	2.2
PLUTO	0	3,675,000,000 mi	248.31^{y}	6.4^{d}	3,600 mi?	0.09?	0.8?	?

*y=year, d=day, h=hour, m=minute, s=second (in earth time units)

**Asteroids have orbits that vary and, therefore, their mean distances from the sun are only approximate. Almost all asteroids are found between 142,000,000 mi and 484,000,000 mi from the sun; that is, they lie between Mars and Jupiter. Because of the number and variety of asteroids, their measurements have been omitted.

***Diameter of ring system.

MAIN IDEAS

1. Ptolemy was an early astronomer who believed that the earth was the center of the universe around which the sun, planets, and stars revolved.
2. Galileo was the first scientist to use the telescope for observation of the moon and planets. He believed that the sun was the center of the solar system and supported the idea first expressed by Copernicus, that the earth was but one of the planets controlled by the sun. By the 17th century, scientists generally accepted Galileo's theory of the solar system.
3. The celestial sphere is used for charting star positions. Declination indicates distances north and south of the celestial equator. Plus declination readings are north, minus declination readings are south of the celestial equator. Right ascension measures positions eastward from the point where the celestial equator and the ecliptic (sun's apparent path) intersect on the spring equinox.
4. Constellations are groups of stars named by Greek and Roman astronomers for objects familiar to them.
5. The gravitational attraction of the sun holds the planets in their orbits.
6. Radiant energy is emitted by the sun during the transmutation of hydrogen into helium gas.
7. The sun consists of the interior, where transmutation of hydrogen occurs; the photosphere, which is the luminous surface we see; the chromosphere, a zone of hot gas surrounding the photosphere, and the corona, a zone of thin gas in which protons and electrons are widely dispersed.
8. Sunspots are areas on the sun's surface in which temperatures are lower than surrounding gases. Sunspots have cyclic periods of activity which affect earth's magnetic field.
9. Planets of the solar system include Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto in this order outward from the sun.
10. Asteroids are fragments of cosmic matter which orbit in a position between Jupiter and Mars.
11. Mars does not appear to have a magnetic field or radiation belts similar to those of earth.
12. Venus' surface is obscured by dense clouds.

13. Photographs of a portion of the Martian surface show many craters similar to those of the moon. Mars atmosphere, which is exceedingly thin, appears to consist principally of carbon dioxide.
14. Jupiter, Uranus, Neptune, and Saturn are known as gas giants because of their great size and low density.
15. Comets follow orbits which are independent of other members of the solar system. If comets collide with other celestial bodies they may disintegrate into small fragments called meteoroids.
16. Meteoroids are called meteors if they enter the earth's atmosphere. Meteoroids are called meteorites if they reach the earth's surface.
17. Meteorites furnish clues to the kind of material from which the planets were formed. The earth's core is thought to be similar to iron meteorites. The earth's mantle may be similar to the stony meteorites.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

ascension	corona	photosphere
asteroid	declination	satellite
celestial sphere	ecliptic	siderites
chromosphere	equinox	transmutation
constellation	meteoroid	zodiac

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Ptolemy and Galileo agreed tnat the earth is the center of the universe.
2. The sun is the star which supplies radiant energy to the solar system.
3. Other planets orbit the sun in nearly the same plane as the planet earth.
4. Stars appear to be stationary because they are very distant.

5. A constellation is composed of several planets.
6. The solar system contains the sun and seven planets.
7. The celestial sphere has the earth at its center.
8. The surface of Venus is obscured by clouds.
9. Planets may be located easily on a star chart.
10. Planets appear to move more rapidly than stars.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. The first astronomer to use the telescope in his study of the stars was (*Ptolemy, Galileo, Kepler*).
2. The idea that the sun is the center of the solar system was first suggested by (*Copernicus, Galileo, Lowell*).
3. The sun's apparent path in the sky is called the (*celestial equator, zodiac, ecliptic*).
4. Planets orbit the sun within an area called the (*celestial equator, zodiac, ecliptic*).
5. Density of the sun is (*greater than, less than, the same as*) the density of the earth.
6. Transmutation takes place in the sun's (*interior, chromosphere, corona*).
7. Of all the planets in the solar system, (*Saturn, Uranus, Earth*) has conditions that are necessary to supporting complex forms of life.
8. The largest planet in the solar system is (*Jupiter, Saturn, Uranus*).
9. Cosmic materials which are burned as they pass through earth's atmosphere are called (*asteroids, meteoroids, meteors*).
10. Siderites, aerolites, and siderolites are types of (*meteorites, meteoroids, meteors*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Measurements in angular degrees north and south of the equator of the celestial sphere are called __?__.

2. The scientist known as the founder of modern astronomy was __?__.
3. Measurements eastward from the position of the intersection of the ecliptic and celestial equator are called __?__.
4. The Big Dipper and Little Dipper are found in constellations known as __?__ and __?__.
5. The sun contains __?__ per cent of the mass of the solar system.
6. Transmutation is a process by which __?__ is changed to __?__ gas.
7. __?__ is the planet which is closest to the sun.
8. A belt containing many __?__ lies between Jupiter and Mars.
9. Three planets which are not visible without a telescope are __?__, __?__ and __?__.
10. __?__ are celestial bodies of cosmic grit and ice which may orbit far into outer space.

D. How and Why

1. How may an observer distinguish a star from a planet?
2. Why was it difficult for people to accept Copernicus' idea that the earth and planets revolve around the sun?
3. Although astronomers know that earth is not the center of the universe, why do they continue to use earth as the center of the celestial sphere?
4. Why is the ecliptic called the "apparent path of the sun"?
5. Why is intersection of the ecliptic and celestial equator used as the starting point for measuring right ascension?
6. What conditions on the surface of Venus make the existence of earth-like life impossible?
7. What conditions on Mars make it seem improbable that animal life as we know it could exist?
8. What kinds of information may be obtained from a study of meteorites?
9. Why does the tail of a comet trail away from the sun?
10. Suggest two reasons why Mercury has not retained a detectable atmosphere although both Venus and Earth have retained their atmospheres.

INVESTIGATIONS

1. Find information on the latest comet and report to the class.
2. Report on Meteor Crater, Arizona. Is the crater correctly named? Do scientists agree on the cause of the crater?
3. Select one of the planets and report on the latest information available.
4. Discuss the work of Clyde Tombaugh, Percival Lowell, or another astronomer.

INTERESTING READING

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*Well-illustrated material.

The Moon

Earth's natural satellite and the nearest celestial neighbor is the moon. Compared to the planets and stars, the moon can be observed easily. Even so, little is known about the moon's composition, its history, or its origin. From samples of the moon's surface materials, scientists may be able to determine the moon's composition, its origin, and perhaps even the origin of the earth.

22:1 *Properties*

For the first time, man saw details of the moon's rugged surface in 1610 when Galileo trained a telescope on the moon. Galileo named the low, dark flat areas of the moon *maria* (mae′ ree a), the Latin word for seas. Each "sea" or *mare* (mae′ree) that has been observed has been given a special name, such as *Mare Nubium* (Sea of Clouds) and *Mare Tranquillitatis* (Sea of Tranquility). Although scientists realize that no water is present in the maria, the original term is still used. Bright areas of the moon are the highlands.

Earth's moon is exceptionally large compared to its planet.

The moon's diameter of 2,160 mi is small compared to most members of the solar system. Nevertheless, in proportion to the size of its primary (the planet earth), the moon is extremely large for a satellite. Jupiter, Neptune, and Saturn have moons that are larger than earth's moon, but, compared to the size of their respective planets, these satellites are extremely small.

Surface features of the moon have changed little because erosion and weathering are not effective. Temperature range on the moon is greater than on earth due to the lack of a lunar atmosphere.

The moon's mass is 8.1×10^{19} tons; its density is 3.3 g/cm^3. Because the moon does not have enough gravitational attraction to hold an atmosphere, few earth-like weathering processes occur. Little or no air and moisture are present on the moon. Consequently, the moon's surface features have remained

nearly unchanged, in contrast to the earth's surface where little remains exactly the same from one day to the next. Temperature on the moon varies greatly. Parts of the moon in shadow may have temperatures as low as —173°C (—280°F). Parts of the moon in direct sunlight may have temperatures ranging from 110°C to 130°C (230°F to 266°F).

22:2 *Motions*

The moon completes one revolution of the earth in 27.3 days, measured in relation to a sighting on a star. At the same time, earth moves forward in its orbit around the sun. Thus, 29½ days pass before the moon arrives opposite the same position of earth from which it started.

During the moon's 27.3-day revolution around the earth, it makes one complete rotation on its axis. (Figure 22–1.) Consequently, the same side of the moon always faces the earth. When that side of the moon is illuminated by sunlight, it reflects some light to the earth as moonlight. A *full moon* occurs when the earth is between the sun and moon. When the moon is between the earth and sun, the *new moon* or the dark period of the moon occurs. *First quarter* and *last quarter* moon occur halfway between the full and dark positions. Less than a quarter is a *crescent moon;* more than a quarter is a *gibbous* (gib′ us) *moon.* (Figure 22–2.) These particular appearances in the cycle of changes are known as the *phases* of the moon.

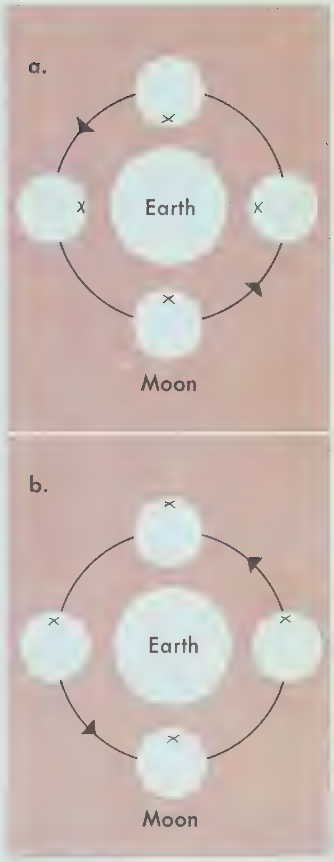


Figure 22-1. (a.) Revolution and rotation periods of the moon are the same. Therefore, the same side always faces the earth. (b.) If revolution interval were the same but the moon did not rotate, both sides would be visible from earth.

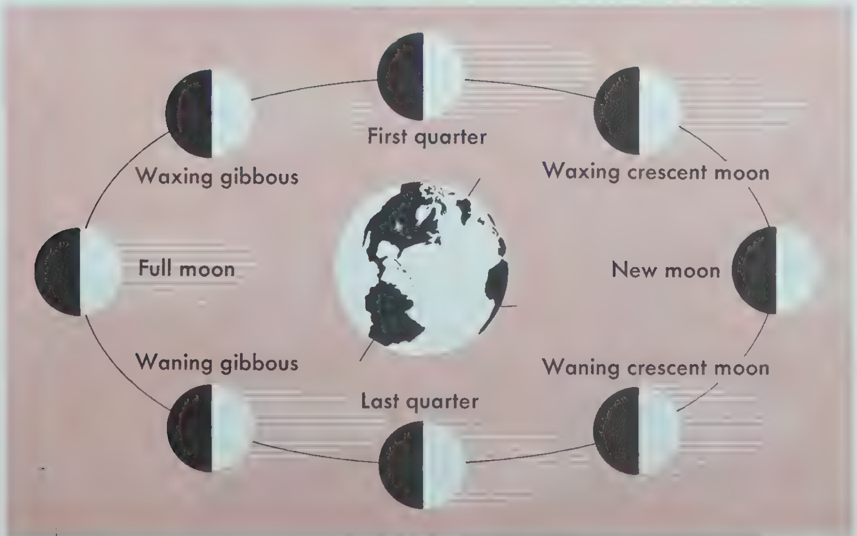
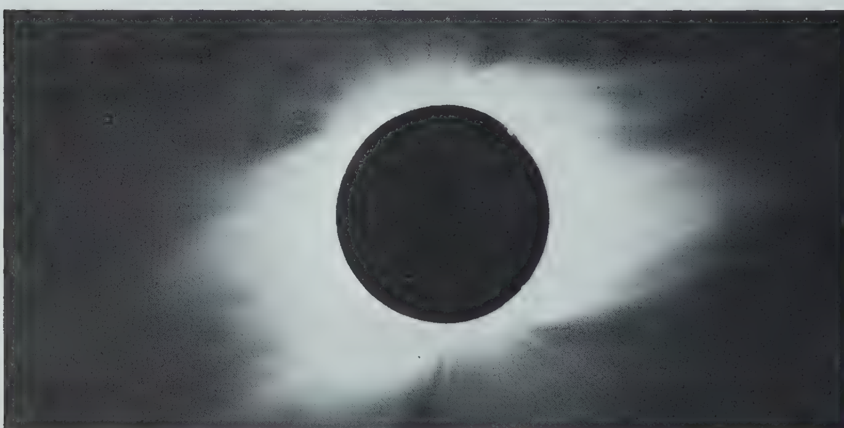


Figure 22-2. Relative position of earth and moon with respect to the sun determines the moon's phase. A complete cycle from new moon to new moon is 29½ days.

Its size and orbit make earth's moon unique among the satellites of the solar system. Satellites of other planets have nearly circular orbits. But the moon's orbit, an ellipse, carries it 253,000 mi from the earth at apogee (ap′a jee) and 221,000 mi at perigee (per′a jee). Also, the angle between the moon's orbital plane and the celestial equator varies from 18½° to 28½° in a period of 18.6 years. Satellites of other planets orbit in the plane of the equator of their respective planets. Because of its large size compared to earth, as well as its *eccentric* (ik sen′trik) or non-circular orbit, and the angle its plane of orbit makes with the earth's plane of orbit, many scientists regard the earth and moon as double, or twin, planets.

Orbit of the moon is elliptical, ranging from 221,000 mi to 250,000 mi from earth.

Positions of earth and moon in relation to the sun often cause one body to pass into the shadow of the other. Then an eclipse occurs. When sun, earth, and moon are lined up in such a way



NASA

Figure 22-3. The sun's corona seen during an eclipse.

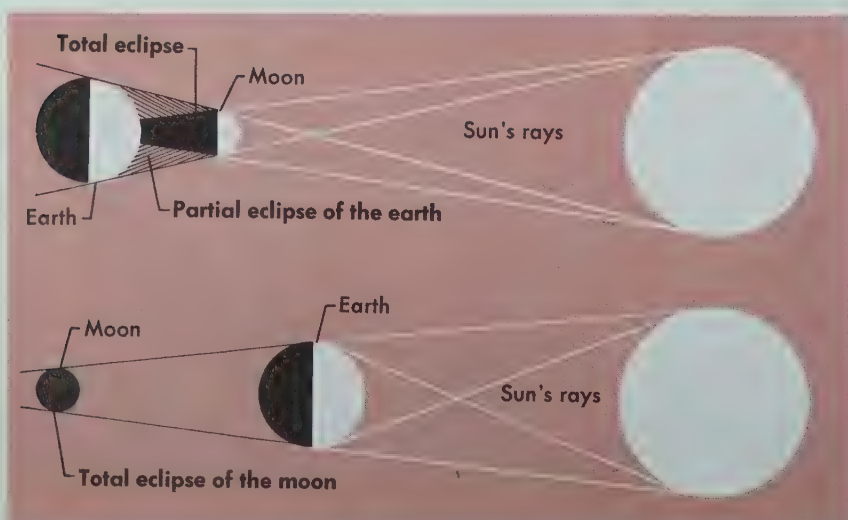


Figure 22-4. An eclipse of the earth occurs when the moon is between the earth and the sun; an eclipse of the moon occurs when the earth is between the moon and the sun.

that the moon lies directly in the shadow of the earth, an eclipse of the moon, or *lunar eclipse*, occurs. If the moon's orbit were exactly around the earth's equator, and if there were no tilting of the axis of rotation, a lunar eclipse would take place with every revolution of the moon. Although only three or less lunar eclipses occur per year, many people have seen them because a lunar eclipse may be viewed from about half of the earth. Because the earth's orbit and the moon's orbit are known precisely, their positions for casting shadows on one another can be calculated and the eclipse can be predicted.

When the moon lies directly between earth and sun, an eclipse of the sun, or *solar eclipse*, occurs. Then the moon shuts out the sun's rays over some portion of the earth. Because the moon is smaller than the earth, only a small segment of earth lies in the path of a total solar eclipse. A larger area has a partial eclipse, but some parts of the earth have no eclipse. During a total solar eclipse, the sun's corona can be studied because the brilliant photosphere is blacked out and only the corona is visible. (Figure 22–3.)

Because of its size the sun is never in total eclipse over the whole earth.

EXPERIMENT. Place a large ball in the middle of a desk or table. Be sure that there is enough room for you to walk around the table. Through the middle of a smaller ball, push a spindle or long nail as an axis. Hold the smaller ball with its axis perpendicular to the table, and mark the side facing the larger ball. Carry the smaller ball around the table and turn it slowly on its axis so that it rotates once during your orbit around the larger ball. Observe the marked side as you turn the smaller ball on its axis. During the orbit, is the mark always in the same position with respect to the larger ball? Discuss why only one side of the moon is visible from earth. How would the view of the moon from earth differ if the moon did not rotate? How would it differ if the moon rotated more rapidly?

Darken the room and again orbit the smaller ball around the larger one. Have another student direct a flashlight beam toward the larger ball on the table. His position should allow you to move the smaller ball between the light and the larger ball. Hold the smaller ball so your body does not shade it from the flashlight beam.

Draw diagrams to show the amount of light reflected from the smaller ball, as seen from the position of the larger ball. What is the position of the smaller ball with respect to the flashlight beam during the phases? On your diagrams, label the various phases of the moon as full moon, crescent moon, quarter moon, gibbous moon, and new moon.

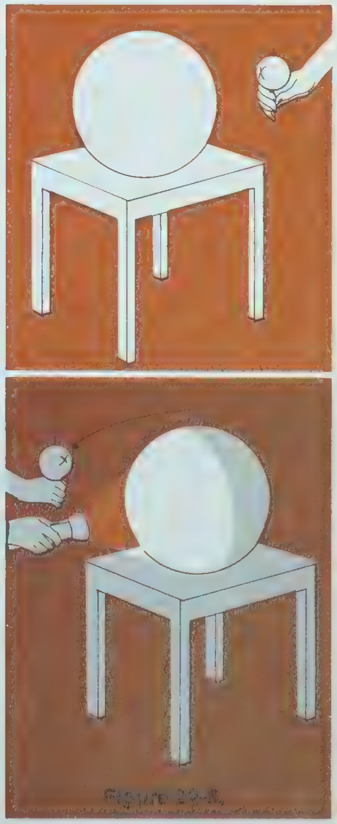


Figure 22–2.

22:3 Earth-Moon System

Center of gravity for the earth-moon system lies 3,000 mi from the earth's center, on the side facing the moon.

Planet earth and its moon revolve around the sun somewhat like a single body. The earth-moon system has a common center of gravity, called the *barycenter*, which is located on the side of the earth facing the moon. (Section 1:4.) The moon orbits the earth due to the gravitational attraction between earth and moon. Without gravity, the moon's inertia would cause the moon to continue moving forward in a straight line. But the gravitational attraction of the earth pulls the moon inward and keeps it moving in an elliptical path around the earth.

In addition, the gravitational attraction of the moon for the earth causes tides to rise and fall within and on the earth. Tides are most apparent in ocean waters. (Section 12:4.) But much tidal energy, estimated at about two billion horsepower, is lost because of friction between adjacent water particles, between water particles and the ocean bottom, and between water particles and the shore. Loss of energy because of tides causes the rate of rotation of the earth on its axis to decrease slightly. Because the length of day depends on the time required for one complete rotation of the earth, any decrease in the rate of rotation results in a longer day.

Energy loss due to tidal friction causes the earth to rotate more slowly with age.

The day is estimated to be slowing at the rate of about 0.0016 sec per century. This is a small amount, but the loss means that positions of bodies in the solar system calculated a century ago are now slightly in error. Future positions of planets may be calculated accurately only when corrections are made to offset the error caused by tidal friction.

George Darwin, a British astronomer and son of Charles Darwin, was an authority on tidal energy. He demonstrated that the slowing of the earth's rotation has an important, long-term effect on the angular momentum of the earth-moon system. **Angular momentum** is equal to the mass of the body times the velocity times the distance of the body from its axis of rotation. It may be written mathematically as follows:

Angular momentum of a rotating body is not lost but may be redistributed.

$$A_m = M V R$$

In this equation, A_m represents angular momentum, M represents mass, V represents angular velocity, and R represents the distance of the body from the axis of rotation.

Conservation of angular momentum applies to the solar system, to the earth-moon system, or to any bodies that rotate on their axes and revolve around each other. The total angular momentum of the system must always remain constant. Ice

Mass of the earth-moon system remains constant, as does its angular momentum.

skaters, ballet dancers, and acrobats use this law while spinning on skates, on their toes, or when suspended from a rope. These performers spin at a low rate of speed with arms extended sideways. If they bring their arms to their sides quickly, they spin at a much higher rate. Entertainers present a spectacular appearance when they go into a fast spin.

EXPERIMENT. Use a turntable with thrust-type ball bearings capable of supporting your weight. The platform should be less than 1 ft above the floor. Oil all bearings to reduce friction; the platform should spin freely with minimum effort. Hold weights of about 5 lb in each hand. Stand in the center of the platform and have another student gently and slowly *start the platform rotating.*

While rotating, extend your arms and the weights about half-way to your shoulders, making a 45° angle with the floor. What happens? Raise your arms and the weights to shoulder height, parallel to the floor. What happens? Continue to rotate and return your arms and the weights to your sides. What happens to the rate of rotation?

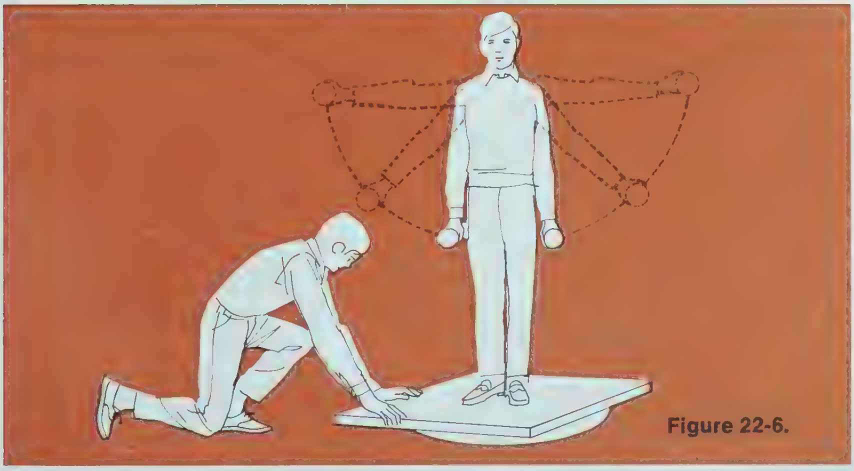


Figure 22-6.

The earth-moon system is also controlled by the law of conservation of angular momentum. When tidal friction loss reduces the earth's angular momentum, the loss is accompanied by an increase in the angular momentum of the moon in its orbit of the earth. Recall from the experiment in Section 1:4 that the velocity of the washer decreased as the length of the string increased. In the earth-moon system, the distance automatically adjusts to any changes in velocity.

Changes in rotational velocity of the earth result in changes of the radius between earth and moon.

Figure 22-7. The earth-moon system would readjust to a change in angular momentum.

Rotational slowing of the earth has been measured from the position of planets which arrive at calculated positions ahead of schedule. Some calculations show the moon to be moving away from earth at the rate of about ½ in./yr. During the earth's approximately 4.5 billion-year life, which probably equals the life of the earth-moon system, even these small changes in position become significant.

Eventually earth's period of rotation may equal moon's period of orbit.

Many astronomers believe that eventually the earth's period of rotation will be the same as the orbital period of the moon. But since the moon is moving away from the earth, the month is lengthening. According to astronomers' estimates, when the earth's period of rotation equals the moon's orbital period, the month will equal 47 of our present days. At that time one earth day would equal 1128 hours.

$$\left(\frac{47\ \cancel{\text{days}}}{} \left| \frac{24\text{ hr}}{\cancel{\text{day}}}\right. = 1128\text{ hr}\right)$$

PROBLEMS

Recall the law of conservation of angular momentum and the formula for angular momentum: $A_m = M\ V\ R$

1. If the distance R is doubled and there is no change in mass M, what happens to the velocity V? Why? Prove that your answer is correct by replacing M, V, and R with numbers.
2. If the distance R is halved and there is no change in mass M, what happens to the velocity V? Why? Prove that your answer is correct by replacing M, V, and R with numbers.

If earth's rotation period would ever equal the moon's revolution period, there would be fixed tides on both moon and earth and, thus, no tidal friction. From what is known today, the earth-moon system would then be stable, if it were not for the effect of the sun's gravitation. At that time, the effect of the sun's gravitation would become the dominant tidal influence. Tidal friction would cause the earth's rotational period to become longer than the moon's period of revolution, and the system would readjust to the change in angular momentum. Then the moon would move back toward earth. When the moon approached within a few thousand miles of the earth, the earth's gravitational field would develop strong tidal forces in the moon. Such stresses would cause the moon to break up into small particles. These particles could orbit the earth as a ring-cloud. Astronomers predict that the disruption of the moon would occur when the moon was still about 10,000 mi from earth. Although the earth's gravitational attraction would hold the earth together, tides of tremendous size would occur and would change the shape of earth's surface. Mathematically, the disruption of the moon can be predicted. But the time involved is so many billions of years that the sun may have burned itself out before these changes in the earth-moon system could occur.

Tidal friction caused by the sun's gravitational attraction would reverse the outward movement of the moon.

Destruction of the moon might be expected as it approached within 10,000 mi of the earth.

Because of tidal friction, some original energy already has been lost from the earth-moon system. The lengthening rotational period of the earth has caused the moon to recede. The increase in distance from the axis of rotation is similar to the outstretching of an ice skater's arms. The decrease in the earth's velocity of rotation has caused a lengthening of the day. Paleontologists have found evidence of the previously shorter day in shells of fossils millions of years old. Yearly growth rings on ancient shells indicate that formerly an earth day was shorter than it is at present.

22:4 *Origin*

As a result of his studies of tidal friction, George Darwin suggested a theory for the origin of the moon. His theory was accepted by astronomers of his day, but today it is regarded as improbable. Darwin believed that tidal calculations could be projected backward in time to an unknown date when earth and moon were close together. Then day and month were equal, and both were about 3 hours to 5 hours long. Because day and month

were the same, the only tidal friction was due to the sun's gravitational attraction. Eventually, the solar tides upset the earth-moon equilibrium and tidal friction carried the moon away from the earth and has continued to do so. Darwin considered it possible that, prior to these events, the earth may have been a highly compressible gas. As the gaseous mass rotated faster and faster, planet earth's volume decreased. However, at some time during this process, outer particles of the gas cloud could no longer be held in place by gravitational attraction, and they flew into space, but remained near the earth mass. Gradually, the discarded particles collected and became earth's satellite. An objection to this theory of the origin of the moon is the fact that the moon does not orbit around the earth's equator. If the satellite had formed as Darwin suggested, the moon should orbit in the plane of the earth's equator. Furthermore, such a moon should be small compared to the size of the planet from which it originated.

Origins proposed for the moon include the theory that it is a part of the earth which became separated during rotation of a large mass in the liquid state.

As an alternate theory, Darwin suggested that the earth originally may have been a liquid mass. As rotation of a viscous

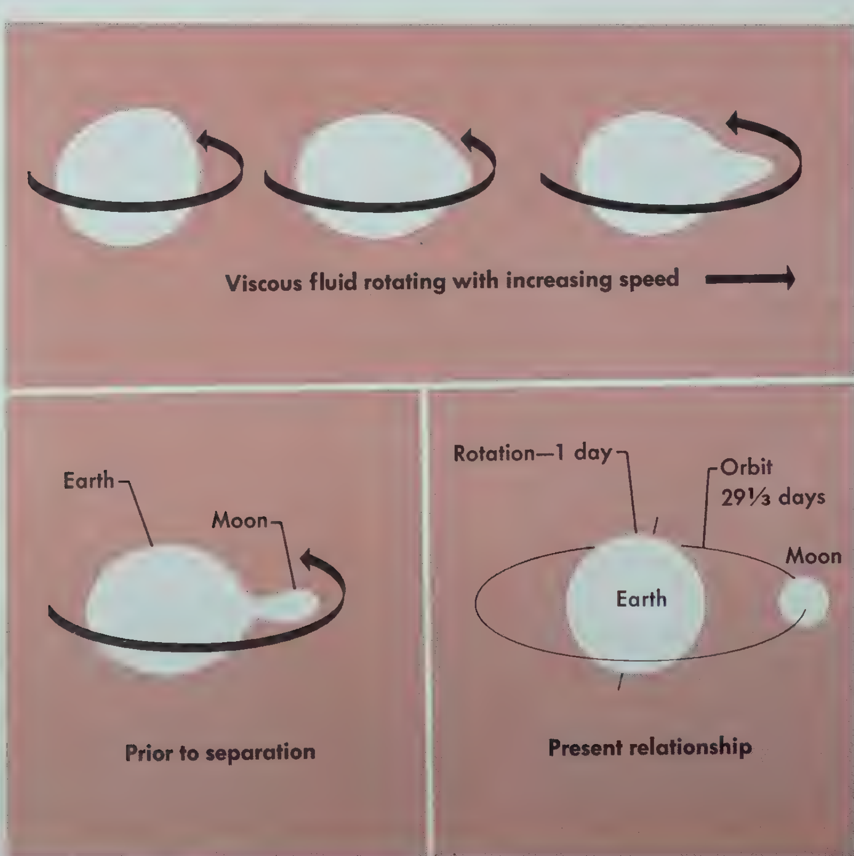


Figure 22-8. Darwin's concept of the moon's origin and its relationship to earth at present.

liquid mass increases, a pear-shaped mass tends to form and, eventually, the mass may have the shape of an hour glass. An outside force might cause the two parts of the hour glass to separate at the neck. This theory could account for the large size of the moon, but astronomers believe the sun's gravitational attraction is insufficient to bring about separation of the hour glass mass. Furthermore, such a satellite should orbit around the earth's equator.

In Kuiper's theory of the origin of the solar system (Section 1:2), he suggested that planets originated in a great mass of rotating gas and dust. Eddies or centers of condensation, called **protoplanets**, developed within the major dust cloud and eventually became planets. He suggested that the protoplanet which became the earth had two centers of condensation. The larger protoplanet condensed and formed the earth; the smaller protoplanet became the moon. Kuiper's theory accounts for a satellite of large size, which need not orbit around the equator. One difficulty with his theory is that the moon is a sphere, and only a rigid material could have retained such a shape when subjected to the tides caused by a nearby planet. To meet this objection, it must be assumed that the moon has been rigid from the time it became a partner in the earth-moon system. Harold Clayton Urey, an American chemist and astronomer, has suggested that the surface of the moon has been loaded by dense material from meteorites.

Kuiper's theory of moon origin suggests that the eddy containing earth's protoplanet developed a second eddy which became the moon.

Another theory suggests that at one time the moon was an independent, small planet. This rigid planet orbited close enough to the earth to be captured by earth's gravitation. Proponents of this idea believe that maria formed when the moon joined the earth in a system. However, theories of the moon's origin are always subject to change.

22:5 *Surface Features*

Although questions concerning moon material remain unanswered, great progress has been made in the study of the moon's surface through the use of unmanned spacecraft. Many irregularities mark the surface of the moon. Some details are visible through ordinary field glasses, and many excellent photographs have been obtained through telescopes. Best information comes from pictures taken from spacecraft. Features of the visible side of the moon have been assembled on a lunar reference mosaic or lunar map prepared by the U.S. Air Force.

Figure 22-9. Clods of fine-grained moon material were displaced by the foot of Surveyor V as the spacecraft skidded to a stop.

NASA

Figure 22-10. Around Crater Tycho, the prominent ray system is brightened during the full moon.

NASA

Only 59% of the moon's surface can be seen from earth, but over 75% of the back side and 99% of the front side have been photographed. Maria make up about one-third of the moon's surface.

Because the moon has an elliptical orbit and it rotates at a constant speed, 59 percent of the moon's surface is visible from the earth. But in October, 1959, the Russian Lunik III orbiting spacecraft supplied the first, but indistinct, pictures of the back of the moon. Spacecrafts of the U.S. Lunar Orbiter program have returned telephoto pictures of the front and the back of the moon. These pictures are used to map the lunar surface.

Mountains, plains, and craters mark the moon's surface. Some craters are so small they cannot be seen from earth even with the best telescopes. Knowledge of these small craters comes from pictures provided by U.S. spacecraft of the Ranger, Surveyor, and Lunar Orbiter series. Some craters are extremely large, and some have craters within craters. The southern portion of the moon's visible side is especially rugged. Craters, mountains, and steep cliffs cover hundreds of square miles. Some mountains are estimated to rise 30,000 ft above the moon's surface, higher than any mountains on earth. Straight cliffs appear to be great fault lines, perhaps similar to the San

Andreas fault line of California. (Section 18:1.) One cliff, the Straight Wall located in Mare Nubium, is about 60 mi long and 1,200 ft high. Photographs returned by Lunar Orbiter 4 revealed a trough about 200 mi long and 10 mi wide, on the back side of the moon near the limb, or outer edge.

Most prominent of the moon features are the **maria**, which make up about one half of the visible surface of the moon. The back side of the moon has a relatively smaller area covered by seas than the front side. These depressions are nearly 2 mi below the brighter, light-colored highlands. Some astronomers have suggested that the dark central region of the maria represents subsidence of a central volcanic vent. The floor is believed to represent lava that welled up from below during subsidence. Other scientists suggest that the upwelling of lava might possibly be due to the impact of large meteorites or even asteroids. Mare Imbrium is one of fourteen principal seas. According to R. B. Baldwin, an American scientist, Mare Imbrium (diameter 700 mi) was probably caused by the impact of a small, low-velocity asteroid with an estimated diameter of approximately 100 mi and a velocity of 2 mi/sec. A smaller asteroid moving at a higher velocity is another possible cause. Mare Serenitatis, Mare Humorum, Mare Nectaris, and Mare Crisium are other circular maria. **Circular maria** are surrounded by rims or ring anticlines beyond which lie the plains.

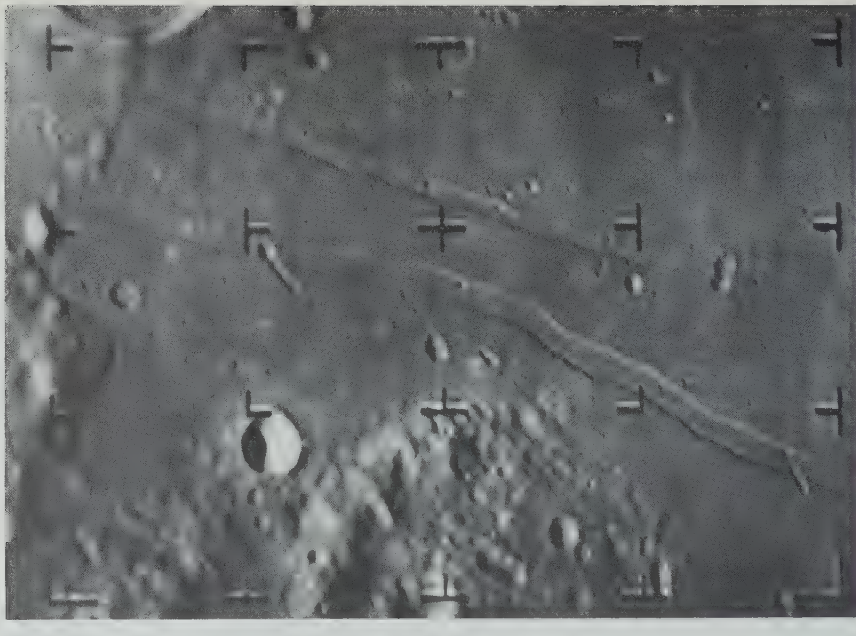
Maria are depressions that may represent subsidence resulting from the internal character of the moon, or possibly due to impact of large meteorites or asteroids.

Maria are thought to be filled by lava from beneath the moon's surface.

NASA

Figure 22-11. Artist's concept of astronaut gathering surface samples from lunar surface.

Figure 22-12. Sea of Tranquility crossed by two long, broad-bottomed rills.


NASA

Their craters are filled with dark gray material which is thought to be lava. The age of the lava flow is estimated to be much less than the age of the craters.

Trenches in the moon's surface which extend across other moon features sometimes for hundreds of miles are called **rills.**

Rills are markings on the moon's surface which have steep sides, flat bottoms, and varying widths. Some rills extend for hundreds of miles and cut across mountains, maria, and other moon landscape features. Because rills often outline the maria, the rills may be associated with lava flows. Some astronomers believe the rills are cracks produced by faulting when the moon material was in the cooling stage.

Wrinkle ridges are complex forms 10 to 20 mi wide that extend for great distances.

In contrast to the rills, **wrinkle ridges** rise above the surface of the moon. Wrinkle ridges have irregular, complex shapes and rather uniform widths. They average less than 1,000 ft in height, and perhaps 10 mi to 20 mi in width, and may extend for great distances. Wrinkle ridges may be caused by compression in contrast to rills which probably are due to tension. Perhaps lava flows in the maria caused crustal bending and sagging of the moon's surface and this movement resulted in tension cracks or rills at the edges of the maria. Compressional ridges, or wrinkle ridges, may have formed in the central part of the maria during movement of moon's surface.

Rays are bright areas on the moon's surface radiating outward from a center like the spokes of a wheel.

Rays constitute one of the most distinctive features of the moon. Rays are the bright streaks that radiate from craters like the spokes of a wheel from the hub. These rays may extend up to 2,000 mi. Ranger spacecraft photographs show small craters located on some rays. A generally accepted theory to account for the rays suggests that they consist of pulverized

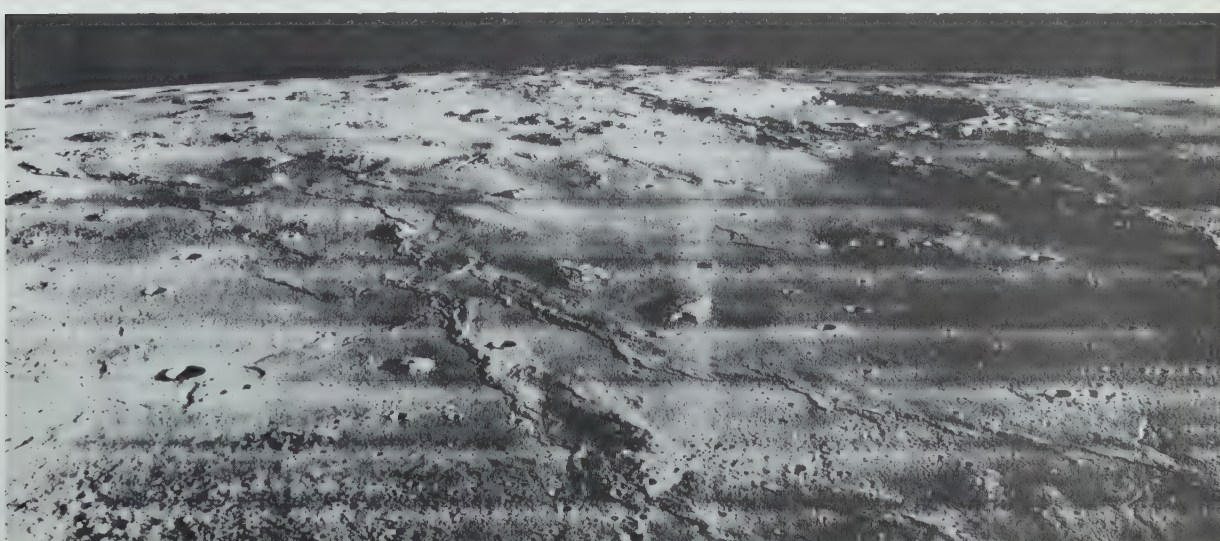
rock, or *rock flour*, which was blasted from the moon's surface material during the formation of a crater. Light-colored rays may darken with age or during bombardment by cosmic material. Not all craters appear to have rays, and it may be that the darkening process makes them impossible to recognize. Rays may be a clue to the relative ages of ray craters as compared to rayless craters. Crater Tycho has a spectacular ray system and is considered to be one of the youngest of the craters.

Craters are prominent features of the moon's surface. Some craters appear to result from causes within the moon itself. Others probably are due to the impact of falling meteorites. **Walled plains** are among the most conspicuous craters. They are from 40 mi to 150 mi in diameter. Within a walled plain, the terrain is almost level except for an occasional crater or mound. They resemble caldera or craters formed by collapse along fault lines. They may have been broken down by gradual erosion due to temperature changes, cosmic rays, or meteoritic bombardment. Some walled plains appear to be the oldest observable features on the moon, but like other moon features, their origin is unknown.

Walled plains on the moon are craters that appear to be due to internal activity.

Explosion craters are numerous and found in all kinds of moon terrain. Their walls are definite, and small craters, called *craterlets*, are common around their rims. Most explosion craters tend to be circular, in contrast to walled plains which tend to be polygonal. Ray systems are another characteristic of explosion craters. The outer edge or limb of the moon that leads, as the satellite moves in its orbit, contains a concentration of

Figure 22-13. Domes on the moon similar to the volcanic domes of Northern California rise 1,000 to 1,500 ft above the surface; diameters are 2 to 10 miles.



NASA

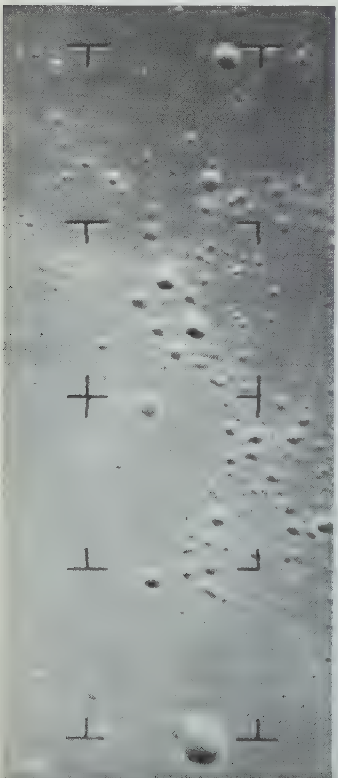
explosion craters. This concentration suggests that the moon meets many meteoroids head-on.

Moon features may be due to both volcanic activity and meteoritic impact.

From the present understanding of the moon, it appears that both volcanic activity and meteoritic impact may account for the moon's features. Some scientists believe that all of the depressions are due to impact. Others believe that all of the depressions are due to volcanic activity. A careful evaluation of all the features seems to require different interpretations for different kinds of depressions.

Evidence for the meteoritic origin of many lunar craters has been gathered during studies of meteorite craters found on earth. Craters formed by chemical and nuclear explosions have received much attention in recent years. A ratio of depth to diameter of explosion craters also applies to meteorite craters on earth and it seems to apply to lunar craters as well. Sizes of craters involved in this study range from 26 ft to about 20 mi. Shapes and relative dimensions of moon craters photographed by the Ranger spacecrafts and by ground-based telescopes agree with shapes and dimensions of meteorite craters on earth. Even larger lunar craters appear to be in such agreement that lunar and earth craters cannot be distinguished. Dimensions of volcanic craters on earth do not appear to duplicate normal lunar craters. Based on this reasoning, the moon's explosion craters appear to be the result of meteoritic impact. Interpretations of lunar features may change with the examination of surface samples from the moon.

Figure 22-14. Crater Copernicus contains numerous secondary craters and this outlying ray.



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Some craters that do not seem to have a meteoritic impact origin are called **chain craters.** These small pits in the moon's surface are less than 3 ft in diameter, and they are aligned in chains extending more than 100 mi. Chain craters are found in the maria. A few extend into the higher, light-colored surrounding area. Chain craters have low rims and probably resulted from violent eruptions of gas which threw out dust and fragments of surface material.

Some observers of the moon have noted that a mist or fog seems to appear over local areas at times. Details that ordinarily can be seen clearly are not visible during periods of fog. Because surface water is not present on the moon, the fog has been attributed to the presence of gas clouds. In 1958, N. A. Kozyrev, a Russian astronomer, obtained spectrograms that indicated weak emissions of gas containing carbon. The gas seemed to come from the central peak of a crater known as Alphonsus. Kozyrev interpreted an observation made in 1959

as similar to volcanic activity on earth. Many astronomers reject this interpretation, but more recent observations of the Alphonsus crater area support the gaseous material emissions.

Space programs have contributed greatly to man's knowledge of the moon's surface features, but composition of the moon remains unknown. Dust, dust and gravel, and lava have been suggested as possible moon materials. Ranger spacecraft photographs of very small craters in the maria indicated that such craters could not persist in loose dust. Further evidence that the moon's surface is not covered with a thick layer of dust was obtained by a Surveyor spacecraft. Surveyor 3 landed in the Sea of Storms, where it used its surface sampler to scoop four trenches in the surface material. Although the trenches were only a few inches deep, photographs showed that the material was *cohesive* (koh hee′siv), or inclined to stick together. It appeared to be soft, but adherent, perhaps like clay or wet sand on earth. Although the photographs do not indicate the composition of material at the moon's surface, they do rule out the probability of thick, loose dust layers. Lava may be present on the moon under a relatively thin coating of the cohesive surface material.

Surveyor landings on the moon indicate that a deep dust layer is not a problem.

Some scientists believe that the moon's surface material consists of fine particles of meteoritic material that has collected during the billions of years since the formation of the moon. Estimates of the amount of "star dust" on earth (Section 21:11), suggest that the moon probably has received similar amounts. Cosmic radiation and bombardment by the solar wind may have baked the meteoritic particles into a soft adherent mass. This material smooths over small pits and cracks in the moon's surface in much the same way that newly fallen snow covers crevasses in a glacier.

Meteoritic particles may cover the moon and form the surface observed from earth.

Most astronomers believe that water is absent on the moon. But V. A. Firsoff, a British astronomer, has suggested that liquid water might be present beneath the surface or, instead of water, layers of ice may be present.

No water has been observed on the moon's surface but beneath the surface layers of ice or water may be possible.

One of the more important results of the moon study has been the application of geology to a mapping project by the Astrogeology Branch of the United States Geological Survey. At first their work was limited to telescope measurements and photographs. But the high quality photographs from spacecraft of the Ranger, Surveyor, and Lunar Orbiter series have aided this project. E. M. Shoemaker, an American astronomer, heads a group which has devised a time scale for major events

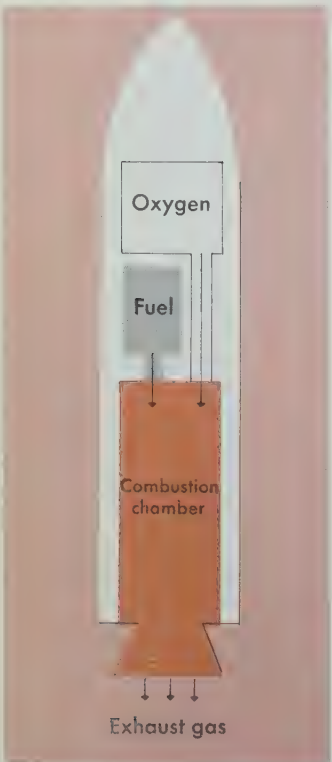
The geologic time scale of the moon has been worked out by using the law of superposition.

on the moon. Using the law of superposition (Section 19:4), the group has determined the ages of various moon features.

Large craters, called **primary craters**, are surrounded by a pattern of small craters known as **secondary craters**. Secondary craters appear on top of some surface features and disappear beneath others. If secondary craters are above, they are younger than the features. If secondary craters are below, they are older than the other features. Based on this kind of information, the Geological Survey has named the lunar periods. The oldest period is called *Pre-Imbrian*. Next oldest is known as *Imbrian. Eratosthenian period* and *Copernican period* follow in that order. This sequence of events was developed for the region of the Mare Imbrium. Shoemaker believes that in time, lunar events can be related to events on earth.

22:6 *Travel to the Moon*

Figure 22-15. Simplified diagram of the internal combustion system of a rocket.



Although space projects already have expanded man's knowledge of the moon, much remains unknown about earth's natural satellite. Astronomers hope to land telescopes on the moon where they can have an unobstructed view of the universe. Earth's atmosphere interferes with telescopic viewing. It contains dust and water vapor through which it is often difficult to see. Air also tends to be in motion much of the time, and motion distorts the view of the heavens from the earth.

Scientists, engineers, and technologists cooperate in building spaceships that can make a safe round-trip to the moon. A spaceship leaving the earth must attain a speed of about 25,000 mi/hr to escape the earth's gravitational pull. However, if the spacecraft left the earth at this velocity, it would bypass the moon and go into orbit around the sun. To hit its target, a spaceship must begin its journey to the moon at a slower speed and use a number of rockets to control its speed and to provide thrust at the proper moment.

The principle of rocketry depends on Newton's law of physics which states that for every action there is an equal and opposite reaction. The recoil of a gun illustrates this principle. When an explosion sends a bullet forward, the gun recoils or moves backward with the same amount of energy that the forward moving bullet has. In a rocket, burning and expelling of gas causes it to move forward with an amount of energy equal to that given off by the gas.

NASA

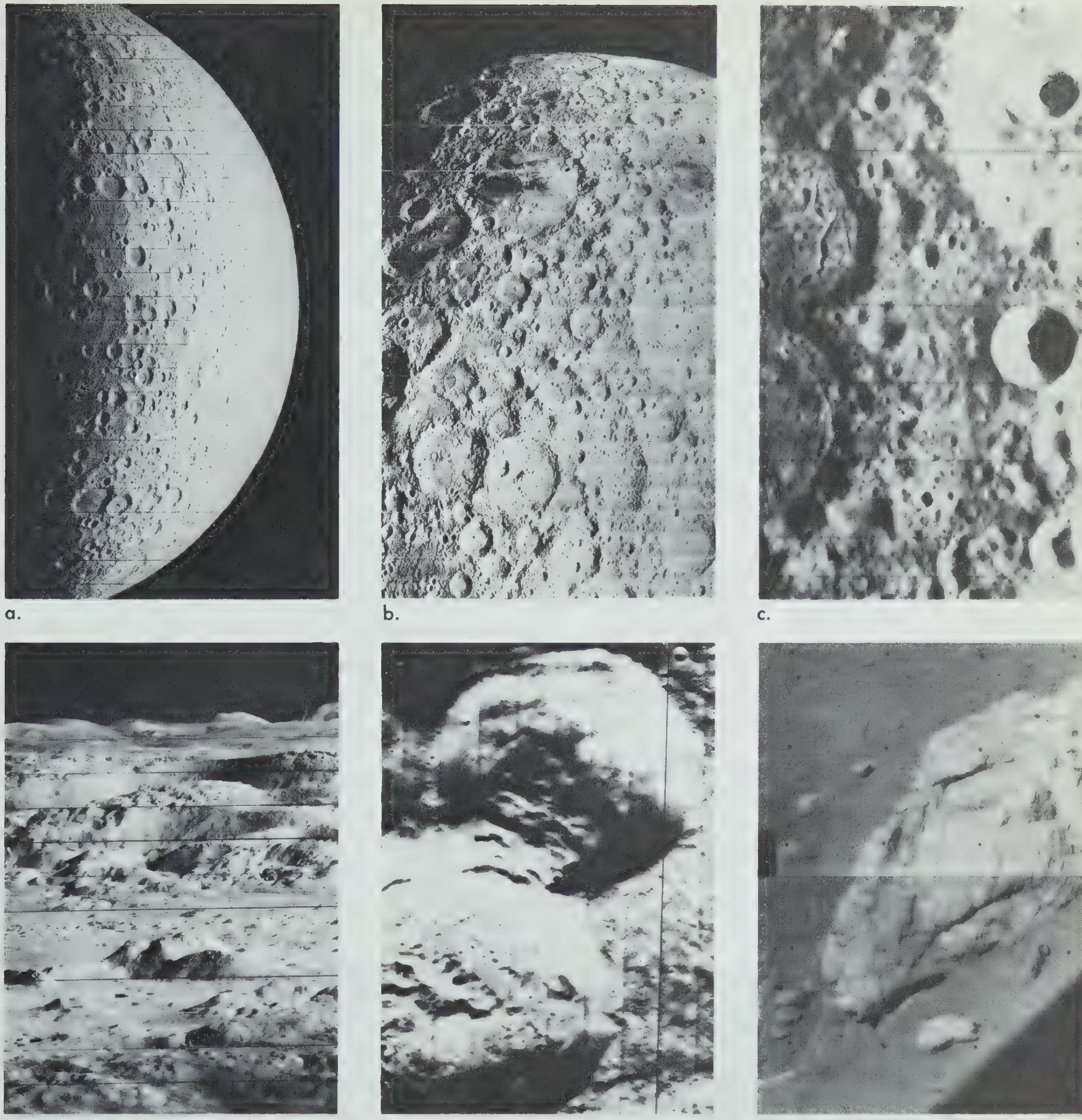


Figure 22-16. (a.) Craters on moon's hidden side, (b.) surface of hidden southern side, (c.) fractured crater floor on hidden side, (d.) portion of crater Copernicus on visible side, (e.) large young crater superimposed on smaller older crater on hidden side, (f.) composite photo of moon material.

Travel to the moon will probably be accomplished in a three-section spacecraft. One section will hold rockets and fuel to be used in maneuvering the spacecraft into a lunar orbit. Another section, the moonship, will carry two astronauts to the moon and back to rejoin a third astronaut in the mothership. Only the mothership will return to earth. The moonship will remain in orbit around the moon. The rocket fuel section will be abandoned just before reentry to the earth's atmosphere.

First men on the moon will be able to stay only a short time because of the absence of water, absence of oxygen, and difficulties of dealing with a different gravitational field. Perhaps the astronauts will encounter other, unforseeable difficulties. Even in the four hours suggested as the maximum time allowed for the first visit to the moon, some questions may be answered. Undoubtedly, the astronauts will discover how to improve future landings and will add to man's knowledge of the moon.

EXPERIMENT. *On a piece of drawing paper, draw a large semi-circle. Divide the arc into fourteen even divisions. Indicate east at the left and west at the right of the arc. (These are not the usual positions for these directions, but because you will face south during your observations, east will be to your left.) Mark the top of the arc as* zenith. *Draw a silhouette of the buildings or landscape features visible when you face south. Include the tallest tree or building as a marker.*

Refer to the daily paper, an almanac, or calendar for the date of the next new moon. Begin your moon watch about two days after new moon. Make your observations at exactly the same time each evening (6:30 is recommended). When the first sliver of the crescent moon appears, add it to your diagram exactly as it appears in the sky. Be sure the points are in the correct position. Locate the moon every night at the same time for at least two weeks. After each sighting, sketch the moon on your diagram. Date each sketch. If clouds obstruct your view, leave a dated space in your diagram. In what

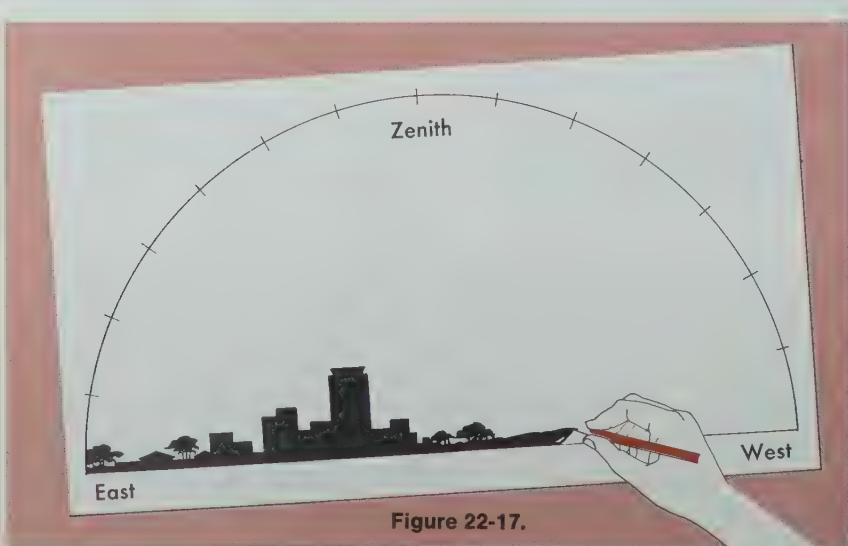


Figure 22-17.

direction do the sketches progress? At the end of two weeks, what is the position of the moon in the diagram? What is its shape? Continue to watch the evening sky at the same time. What do you observe about the moon?

EXPERIMENT. Draw a chart similar to Figure 22–18. Locate the date of full moon and the time at which the moon will rise on that date. Begin your observations on the day when the moonrise is at sunset. On your chart, record the date and the exact minute at which you see the moon rise. Does your data agree with the official time for moonrise? For one week, record the date, the time of moonrise, and the shape of the moon on your chart. Use information from a newspaper to complete the moonset column. How much later is moonrise each night? If the moon rose at 6:00 PM on Monday, what time would it rise on the following Sunday? Did you observe the moonset at any time during the week?

Use binoculars or a telescope to observe the full moon and its surface features. What features account for the moon's "face"? Why does the moon's face seem to turn from side to side on succeeding nights?

MOON CHART

Date	Moon rise	Moon set	Moon shape
10/5/68	6:32 P.M.	7:10 A.M.	Full moon

Figure 22-18.

Table 22-1. ***The Moon***

Mean distance from earth		238,857 mi
Mean diameter		2,160 mi
Volume		53×10^{8} mi^{3}
Mass		8.1×10^{19} tons
Density		3.3 g/cm^{3}
Temperature	Noon	110°C to 130°C (230°F to 266°F)
	Midnight	−173°C (−280°F)
Synodic month (from new moon to new moon)		$29^{d}\ 12^{h}\ 44^{m}\ 2.8^{s}$*
Sidereal month (measured from star position)		$27^{d}\ 7^{h}\ 43^{m}\ 11.5^{s}$
Axial rotation		$27^{d}\ 7^{h}\ 43^{m}\ 11.5^{s}$
Mean orbital velocity		2,287 mi/hr
Inclination of equator to orbital plane		6° 41′
Inclination of orbital plane to ecliptic		5° 08′ 43″
Nutation		18.6 y
Surface	Observable	59%
	Always visible	41%
	Never visible	41%
	Alternately visible	18%

*y=year, d=day, h=hour, s=second (in earth time units)

MAIN IDEAS

1. The moon is a sphere which orbits the earth in an elliptical path. The moon's orbital plane intersects the celestial equator at an angle varying from 18½° to 28½° within an 18.6 year cycle.
2. Because of its large size compared to earth and eccentricities of its orbit, astronomers suggest that earth and moon may at one time have been separate planets. Possibly they may have originated in separated eddies or within a larger eddy during formation of the solar system.
3. Center of gravity for the earth-moon system lies on the side of the earth facing the moon. The system has a constant angular velocity, but changes in the rate of rotation of earth have caused the distance between earth and moon to increase.
4. An increase in the length of day on earth has resulted from tidal friction. Astronomers have predicted that, in billions of years, day and month will be approximately the same length and tides due to the moon will be fixed. Tides caused by the sun will then be a dominant influence and will upset the equilibrium of the earth-moon system, decreasing the length of the day to less than the length of the month. Moon movement will then reverse, the moon will approach the earth to within 10,000 mi and break up into small pieces which will continue to orbit the earth.
5. In one of his theories, Darwin stated that at one time earth and moon were part of a large liquid mass which separated, and that the moon has since moved away from earth to its present position.
6. Only 59% of the moon's surface is visible from earth. Orbiting spacecraft have photographed the back and the front of the moon.
7. The surface of the moon is marked by mountains and various sized depressions which include maria, the largest; walled plains, next largest and probably oldest features of the moon; rills, or trenches; rays, light-colored streaks dispersed like the spokes of a wheel; explosion craters, probably due to meteoritic impact; and chain craters, perhaps caused by gases escaping from beneath moon's surface.
8. Surface materials of the moon may include lava, gravel, and meteoritic particles in a cohesive mass.

9. A geologic time scale for the moon has been worked out by using the law of superposition.
10. Travel to the moon will be in a space ship, containing three sections. The mother ship will make the round trip, but will not land on the moon. A section carrying rockets will be abandoned upon re-entry in the earth's atmosphere. The moon-ship will carry two astronauts to the moon and back but will be abandoned in an orbit around the moon when astronauts return to the mother ship.
11. Escape velocity of 25,000 mi/hr required to leave the earth's gravitational field will be attained in space after the initial thrust has sent the space ship into orbit. Rockets operate on the Newtonian principle that for every action there is an equal and opposite reaction. Expulsion of gas from the rear of the ship causes forward thrust.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

angular momentum	eclipse	rays
chain craters	gibbous moon	rills
cohesive	maria	walled plains
crescent moon	protoplanet	wrinkle ridges

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Dark areas on the moon which sometimes look like seas are really depressions.
2. Earth's calendar month is longer than the time required for moon's orbit around the earth.
3. The moon is the smallest planet in the solar system.
4. Moon's atmosphere is humid.
5. Earth is the only planet which has a moon.
6. Some scientists believe that the moon was once an independent planet.

7. The same side of the moon always faces the earth because the moon does not rotate.
8. An eclipse of the moon occurs when the moon is in the earth's shadow.
9. Ocean tides on earth are caused mainly by the moon's attraction for the earth.
10. Earth's rotation rate is being slowed because of tides.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. The moon's density is (*less than, the same as, greater than*) the density of the earth.
2. The moon's surface is weathered (*more than, about the same as, less than*) the earth's surface.
3. Moon's rotational period is (*24 hours, 708 hours, 27.3 days*).
4. A total solar eclipse may be observed occasionally (*over all, in a small part, in no part*) of the earth.
5. Moon's diameter is approximately (*1,560, 2,160, 25,600*) miles.
6. When half of the moon is seen on earth, it is the (*crescent, gibbous, full*) moon.
7. Travel to the moon will require the use of the principle of (*superposition, rocketry, dominance*).
8. Astronomers will be able to study the universe better from the moon because (*planets and stars will be closer, the moon has little or no atmosphere, the moon does not rotate*).
9. At the present time, (*the moon is moving away from the earth, the moon is approaching the earth, the earth is increasing its velocity of rotation*).
10. Moon surface features which resemble spokes of a wheel are called (*rills, wrinkle ridges, rays*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. Because of earth's gravitational attraction and the moon's inertia, moon's orbit is __?__.

2. A solar eclipse aids the study of the sun's __?__.
3. The center of gravity of the earth-moon system is called the __?__.
4. The moon returns to the same place in its orbit of the earth in __?__ days.
5. When the lighted portion of the moon appears to be convex, but not quite round, it is called a __?__ moon.
6. Mass of a body times velocity times distance of the body from the axis of rotation give the __?__.
7. The most prominent and first observed features of the moon's surface are the __?__.
8. Explosion craters on the moon appear to have been caused by __?__.
9. Astrogeologic study has determined the age of moon features by using the law of __?__.
10. The principle of physics which says that for every action there is an equal reaction, first stated by __?__, is used in the study of __?__.

D. How and Why

1. Why is the moon's surface more ancient than the present surface of the earth, if both earth and moon were formed at the same time?
2. Compare the age of the moon's surface with the age of Mars' surface.
3. What forces are acting on the moon's orbit that cause it to be an ellipse?
4. How does a study of earth's meteorite craters help interpret the craters of the moon?
5. What is the significance of the alignment of chain craters? Why are these craters not generally thought to be of meteoritic origin?
6. Why is the fog noted occasionally in some areas of the moon interpreted as a gas other than water vapor?
7. If the velocity of earth's rotation were to increase, what effect would it have on the moon's distance from earth? What theory of moon origin is based on a backward in time projection of this relationship?
8. How can the Astrogeology Branch of the U. S. Geological Survey set up a geologic time scale for the moon events?

9. Before Surveyor landings on the moon, some astronomers expected the surface to be covered with a layer of dust, perhaps a hundred or more feet deep. What evidence may have changed some of their minds?
10. Why did Galileo call the large depressions on the moon maria?
11. Why must the moon spaceship carry rockets?

INVESTIGATIONS

1. Report on the latest solar eclipse. Discuss the dangers in observing the sun during an eclipse. What advice could you give to an observer?
2. Through library reading, investigate myths about the moon. Find an Indian myth as well as the more common Greek and Roman myths.
3. Report on recent moon flybys and both hard and soft landings on the moon. Discuss Russia's explorations as well as those of the United States.

INTERESTING READING

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Page, Thornton, and Page, Lou Williams, *Neighbors of the Earth*. New York: Macmillan, 1965.

Sutton, Felix, *The How and Why Wonder Book of the Moon*. Columbus, Ohio: Charles E. Merrill Books, Inc., 1963.

Trinklein, F. E., and Huffer, C. M., *Modern Space Science*. New York: Holt, Rinehart and Winston, Inc., 1961.

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* Well-illustrated material.

Stars and Galaxies

Beyond the solar system are countless stars. Some stars are visible to the unaided eye; some can be seen only with the aid of a telescope; still others can be located only through instruments such as radio telescopes. Man has devised a number of instruments with which to investigate the universe. Astronomical distance remains a barrier to travel to the stars.

23:1 *Radiant Energy*

Most present knowledge about the universe is based on observations and measurements of radiant energy.

Knowledge of the universe is obtained by observing, recording, or measuring some kind of radiant energy. Light, heat, and radio waves are familiar forms of this energy. But radiant energy also includes television waves, infrared radiation, ultraviolet rays, X rays, and gamma rays. All radiant energy forms are arranged in the order of their wavelengths in an **electromagnetic spectrum**. In the complete electromagnetic spectrum, wavelengths vary from trillionths of a millimeter to thousands of kilometers. For convenience, the spectrum has been divided into regions of different wavelengths. (Table 23–1.)

Only part of the electromagnetic spectrum is visible.

All known forms of radiant energy travel with a velocity of approximately 186,000 mi/sec. Each form of radiant energy can be distinguished by its wavelength or frequency. **Wavelength** is the distance between successive wave crests. **Frequency** is the number of radiated waves per second.

Forms of radiant energy are distinguished by wavelength or frequency.

With the aid of powerful telescopes, astronomers can see distant stars and recognize differences in their size, color, and brightness. With auxiliary instruments, astronomers also have identified elements within the stars and have discovered the process by which stars radiate energy. Each element in a star radiates energy with its own wavelength or frequency and, therefore, elements can be recognized in the star's spectrum.

Elements may be identified in a star's spectrum by wavelength or frequency.

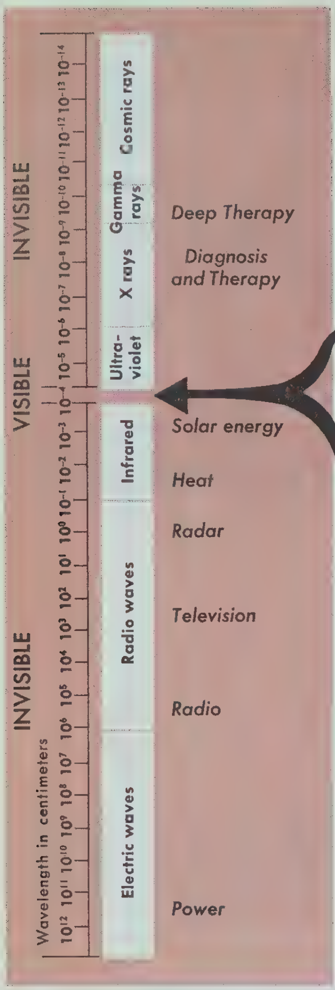
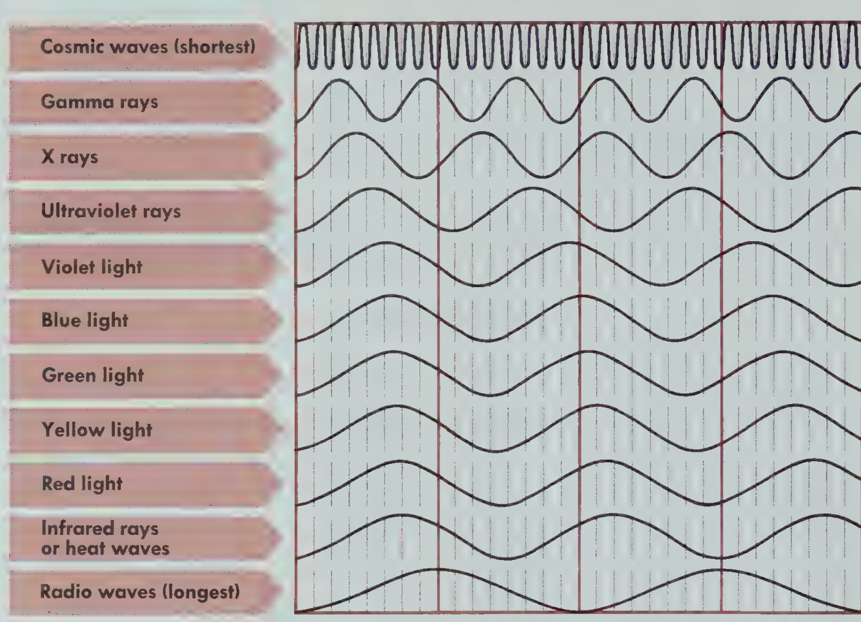


Figure 23-1. Electromagnetic spectrum.

Table 23-1. *The Electromagnetic Spectrum*



By means of an instrument called the **spectroscope** (spek′tra skohp), visible light may be separated into a pattern called the *visible spectrum.* A similar separation of sunlight occurs after a rainstorm when raindrops disperse light into many colors to form a rainbow. Each color of the visible spectrum has a distinct wavelength or frequency. Colors always appear in the same order—violet, indigo, blue, green, yellow, orange, and red. Violet light is at one end of the spectrum with the shortest wavelength or the highest frequency. Red light, at the other end of the visible spectrum, has the longest wavelength or the lowest frequency.

EXPERIMENT. Cut a narrow slit in a square of cardboard so a thin beam of light shines through. Place a prism and the cardboard in the sun so a beam of light strikes the prism. Attach a piece of drawing paper to a clipboard and place it perpendicular to the beam of light so light will be dispersed on the paper. Indicate the bands of color on the paper. (Figure 23–2.) Do colors blend into each other or do they have distinct divisions? Use matching colors of chalk to color the bands of light as they appear in the spectrum. Which color is refracted, or bent, the most? Which color is refracted least? Which color has the longest wavelength? Which color has the shortest wavelength? Why does the sun appear to be red during sunset and sunrise? Which colors in a rainbow are most distinct and persist longest in the sky?

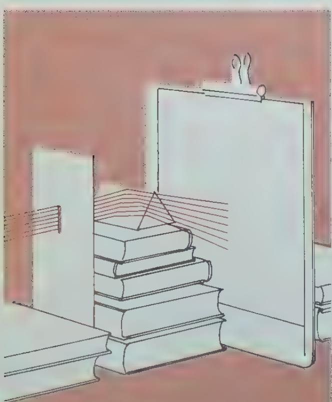


Figure 23-2.

One **light year** is the distance that light travels during one year. Since light travels at approximately 186,000 mi/sec, a light year is equal to 5,865,696,000,000 mi/yr or nearly six trillion mi/yr (6×10^{12} mi/yr). Because light from even the closest stars requires several years to reach earth, you see stars and galaxies as they were years ago, not as they exist today! Astronomers use light years in measuring astronomical distances beyond the solar system.

One light year equals six trillion mi/yr.

Light from the stars is studied by means of the spectroscope. A star emits a *continuous spectrum* which includes most light wavelengths or frequencies. Dark lines, called *absorption lines*, cross the continuous spectrum where certain wavelengths or frequencies have been absorbed by the star's surface gases. Radiant energy from a star's interior passes outward through cooler surface gases which absorb some wavelengths or frequencies. Cool gases tend to absorb their own wavelengths or frequencies from the radiant energy and to leave gaps in the star's spectrum where these wavelengths or frequencies should be. By comparing a star's spectrum to the known wavelengths or frequencies of elements, the presence of certain elements in the star is indicated if wavelengths or frequencies match. In this way, astronomers use the spectrum of a star to determine its chemical composition.

Stars emit light wavelengths or frequencies in a continuous spectrum crossed by dark lines.

Elements whose wavelengths or frequencies match a star's spectrum are present in the star.

In addition to studying the chemistry of stars, astronomers use the spectroscope to find the direction and speed with which a star is moving in relation to earth. Spectral lines shift toward the violet end of the spectrum when a star approaches earth; they shift toward the red end of the spectrum if movement is away from earth. Known as the **Doppler** (dahp′ler) **effect** for the Austrian physicist, these shifts have been observed for

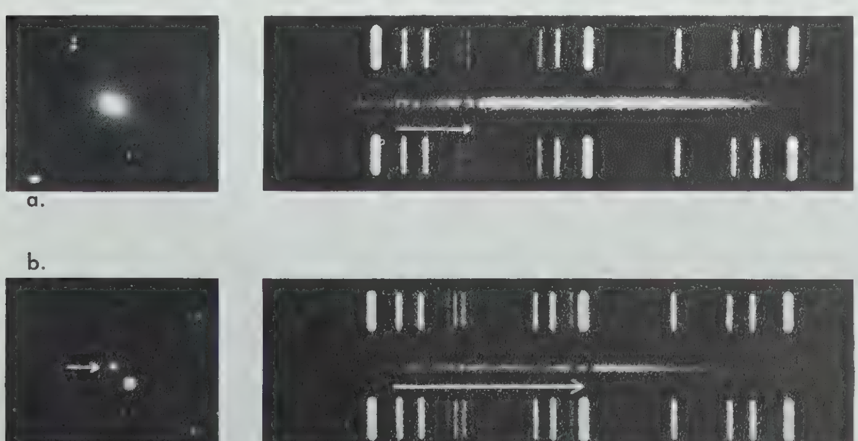


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Figure 23-3. (a.) The red shift for Ursa Major is 9,300 miles per second; its distance from earth is 100,000,000 light years. (b.) Bootes' red shift is 24,400 miles per second; its distance from earth is 230,000,000 light years.

thousands of stars over a period of many years. The Doppler effect may be compared to the characteristics of approaching sound waves. As you wait for a train to approach, the frequency of the sound waves increases and the pitch becomes higher and higher; as the train passes and moves farther away the frequency of the waves decreases and the pitch becomes lower and lower.

Violet light has high frequencies or short wavelengths; red light has low frequencies or long wavelengths. Approaching stars produce lines shifted toward the violet end of the spectrum. Stars receding from earth produce lines shifted toward the red end of the spectrum. But galaxies show only a red shift, according to present observations, and seem to be moving away from earth.

23:2 *Stars*

Parsec is a unit of measure for interstellar space, equal to 3.26 light years.

Stars are self-luminous spheres of gas. Some stars appear bright because they are relatively near the earth; others appear bright because they are massive and give off more radiant energy. Stars are classified according to their brightness or *magnitude* (mag′na teud). In order to have a standard by which to compare stars, astronomers calculate the brightness a star would have at a distance of 32.6 light years (10 parsecs). This brightness is called **absolute magnitude. Apparent magnitude** is the brightness of a star observed at its actual distance from earth. If no dust or gas is present to interfere with visibility, apparent brightness of a light source decreases with the square of the distance from the observer. If the distance is known, the absolute magnitude can be computed from the apparent magnitude. (Figure 23–4.)

Figure 23-4. Surfaces A, B, C, and D illustrate that the amount of light reaching an object varies inversely as the square of the distance (d) from the light source (I_s). The brightness (I) at any distance from the source may be written mathematically as $I = \frac{I_s}{d^2}$.

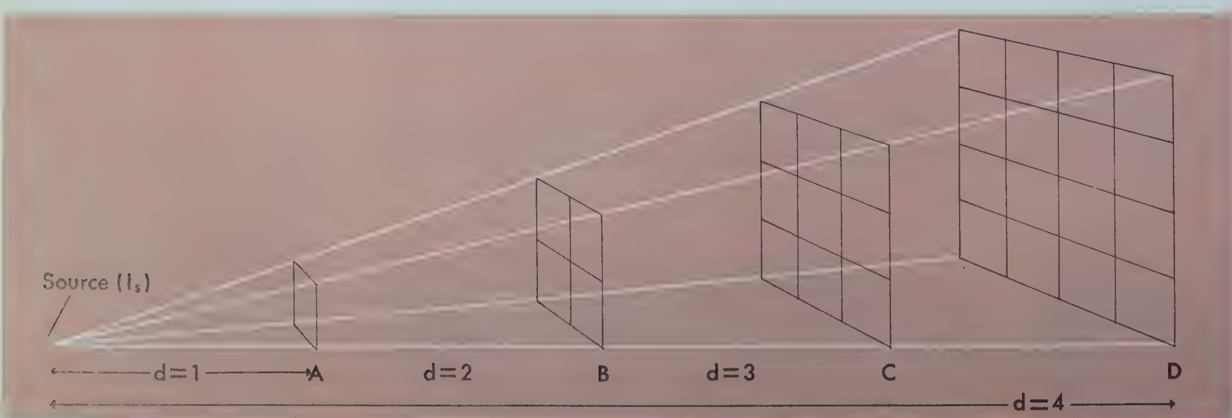

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Figure 23-5. The great cluster of Hercules, at least 100 light years across, contains more than 50,000 stars bright enough for observation and probably many dwarf stars too small to be recognized at a distance of 35,000 light years from earth.

Stars form when concentrations of interstellar matter condense and become self-luminous.

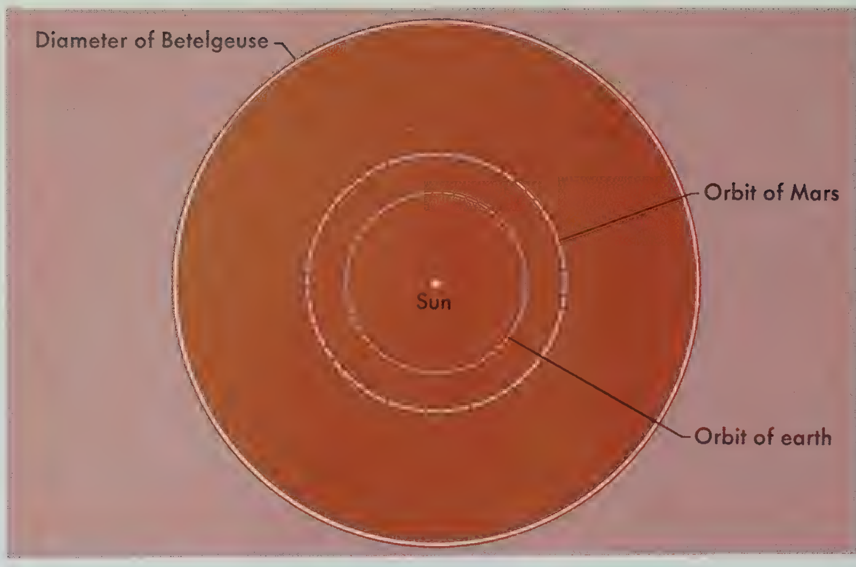
It is generally believed that stars are formed from nebulae, or concentrations of interstellar matter. The most accepted theory of star formation states that dense clouds of dust and gas, about one light year in diameter, may condense to form a star. Stars also may form from the condensation of masses of interstellar material equal to about 1,000 suns. A nebula this large may break up into many parts during condensation and thus form clusters of stars. Condensation or collapse of a nebula is due to self-gravitation. Temperatures within the nebula rise higher and higher as condensation takes place. Eventually, temperatures are high enough for the transmutation of hydrogen to helium. At this stage, the mass begins to emit radiant energy and a star is born.

Stars become luminous when transmutation of hydrogen to helium begins.

According to this theory, a star maintains a relatively constant size, shape, and brightness during most of its life. Radiant energy is released at the star's surface at the same rate that it is formed in the interior. A star remains in equilibrium until most of the hydrogen has been changed to helium. When the hydrogen in the star's core has been consumed, the core collapses and temperatures rise once more. Then transmutation of hydrogen begins in the star's outer gaseous envelope. These outer layers expand and the star brightens.

The final stage in a star's evolution occurs when all the fuel for nuclear reactions has been consumed. Then the star collapses and becomes an extremely dense sphere, which continues to shine as it emits its remaining internal heat. Eventually, the heat will be exhausted and the star will become dark. This entire process may take more than 100 billion years.

Figure 23-6. Betelgeuse, 275 light years from earth, has a diameter ranging from 260 to 360 million miles. This diameter is greater than the diameters of the orbits of earth and Mars.



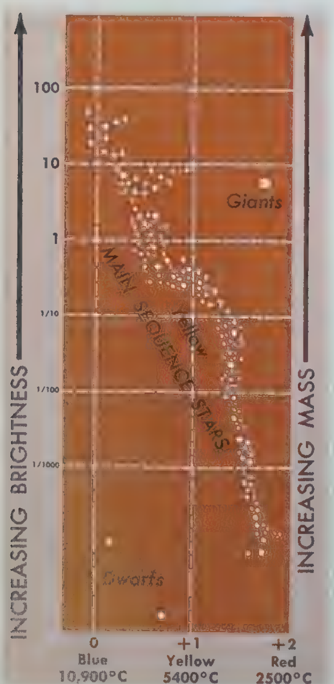
Astronomers have classified stars. Stars in the state of equilibrium are called **main sequence stars**. In contrast to these "normal" stars which are in equilibrium, are abnormally large, massive, bright stars known as **giants** or **supergiants**. Both giants and supergiants are in an advanced stage of evolution in which the hydrogen of the core has been consumed and nuclear reactions are in progress in their outer layers. Supergiants are brighter and more massive than giants, and much more rare.

White dwarfs (which are not necessarily white) are faint stars in the last stage of stellar evolution. They are so dense that electrons and protons do not form normal atoms. Little space is present between the particles of matter. In fact, one cubic inch of white dwarf material would probably weigh about one ton!

Stars vary in color according to temperature. Main sequence stars arranged according to both mass and temperature are blue, white, yellow, and red. Blue stars are most massive; red stars are known as dwarfs. Giants may be either red or yellow; supergiants may be white, blue, yellow, or red. Blue stars have surface temperatures of about 20,000°C (36,000°F). White stars' surface temperatures are approximately 9,000°C (17,000°F); yellow stars' temperatures are about 6,000°C (10,000°F); red dwarfs range from 2,200°C to 3,700°C (4,000°F to 7,000°F).

Variable stars vary in brightness either because of some characteristic within a star, or because of conditions outside the star. Variable stars include novae, supernovae, cepheids, and eclipsing stars.

Figure 23-7. A star's position in this Hertzsprung-Russell diagram is determined by plotting its absolute magnitude and its temperature.



Novae (noh′vee) and **supernovae** brighten rapidly, then gradually dim. In some stars the magnitude increase occurs only once; in others recurring bursts of brightness take place. Supernovae are more massive than novae, but otherwise the two are similar.

Novae and supernovae differ in mass, but otherwise are similar.

Supernovae become extremely luminous, then dim as they lose mass. The Crab Nebula is a remnant of a supernova observed by Chinese astronomers in 1054 A.D. The Chinese observed an exceptionally bright star over a period of two years; then the star disappeared from view. Now the Crab Nebula is recognized as a source of radio noise, X rays, and visible light produced by a mass of expanding gases. A similar brilliant star was observed in 1572 by Tycho Brahe, a Danish astronomer. Six or seven such supernovae have been reported during the past 2,000 years. Although such stars may become invisible, their radio waves and X rays persist.

Supernovae lose mass and some disappear after a period of exceptional brightness.

Cepheids (see′fee ids) belong to the class of variable stars that have periodic pulsation. These stars are not in equilibrium and, consequently, the star's outer layers expand and contract. During expansion, surface temperatures decrease; during contraction, surface temperatures increase. Differences between the maximum and minimum temperatures may be about 700°C to 1,200°C (1,300°F to 2,200°F). When the star is hottest, it is yellow; as it cools, it becomes orange.

Cepheids are variable stars that have regular pulsations.

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Figure 23-8. Crab Nebula in Taurus, a remnant of a supernova, consists of rapidly moving electrons at the center surrounded by outward expanding gases.

Cycle of a Cepheid is used to calculate a star's distance from earth.

Cepheids pulsate with almost perfect regularity. The more luminous the star, the longer its cycle. Therefore, the length of the cycle is a clue to the true brightness or absolute magnitude of a Cepheid. Distance from earth also can be calculated from a Cepheid's cycle. In order to use the Cepheid cycle as a scale for measuring distance, astronomers assume that Cepheids in distant galaxies have the same brightness to pulsation relationship that is shown by nearby Cepheids. Harlow Shapley of the Mount Wilson Observatory discovered that bright massive Cepheids have longer cycles than small dim Cepheids.

By observation, an astronomer finds the apparent magnitude of a Cepheid. He then determines its absolute magnitude by the length of its cycle. Observations of apparent magnitude are put on graphs from which distance and magnitude can be determined directly. Since brightness decreases with the square of the distance from the source of light, the following formula can be used to calculate distance to a star, if its apparent magnitude and true magnitude are known.

$$I = \frac{I_0}{d^2}$$

Where I_0 represents luminosity at a distance of 32.6 light years; I represents luminosity at distance d from observer.

Eclipsing variables are two stars of different brightness that orbit a common point.

Eclipsing variables are stars that change magnitude because they have partners that are dim. The two stars orbit around a common point. An observer alternately sees a bright light followed by a dim light apparently coming from the same point in the sky.

Figure 23-9. Eclipsing variables change magnitude as the brighter star of a pair passes behind the darker star.

EXPERIMENT. Study a star chart until you can locate at least four major constellations in the northern sky. These northern constellations seem to circle the North Star, Polaris *(pa lar'us). Polaris is the apparent extension of the North Pole into the celestial sphere.*

Make the following observations of the sky with the help of one or two companions. On a clear, moonless night at 8:00, stand outside where you have an unobstructed view to the north. Use a compass to find true north. Starting at the horizon, look gradually toward the zenith until you locate Polaris, the bright star exactly north of your position. Two patterns of stars will guide you. Polaris is the last bright star in the handle of the constellation called the Little Dipper. *The two bright stars that make up the bowl of the* Big Dipper *are called the* Pointers *because they are always in a straight line with Polaris.*

Use a string with a weight on one end and a pencil on the other. Point the pencil at Polaris and let the string hang free for a guideline to the position of the stars. Plot these positions on a sheet of drawing paper and mark each star with X_1. You should have plotted the stars of both the Little Dipper and the Big Dipper. Repeat this procedure again at 9:00. This time mark each star position with X_2. Do the X_1 stars and the X_2 stars form the same pattern? If there is any change, what is it? Does this prove that the stars are moving?

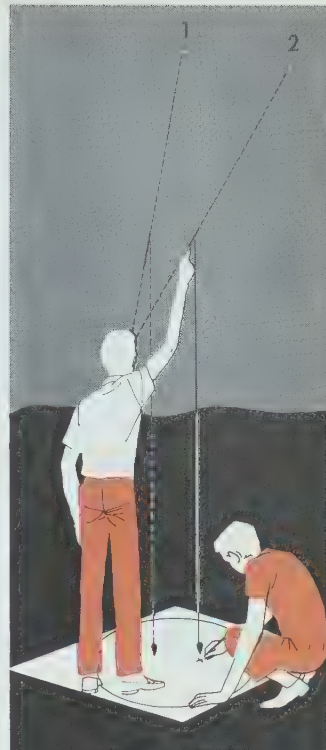


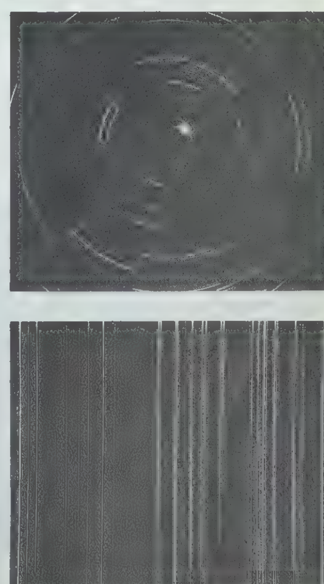
Figure 23-10.

EXPERIMENT. Use a camera which has a time exposure control and which can be braced, and the most sensitive film available. Go outside just after dark on a clear, moonless night. Locate Polaris and arrange the camera so that Polaris is in the center of the lens. Brace the camera in this position and set the focus on infinity. (Figure 23–11.) Open shutter for a time exposure. Leave the camera set up for two hours and then close the shutter.

Note: Explain the nature of the film to your dealer and request that the film be developed with great care. What does the print show? What are the lines in the picture and why do they curve? What is the most central point of light?

Figure 23-11.

Figure 23-12. Compare these star trails with yours.



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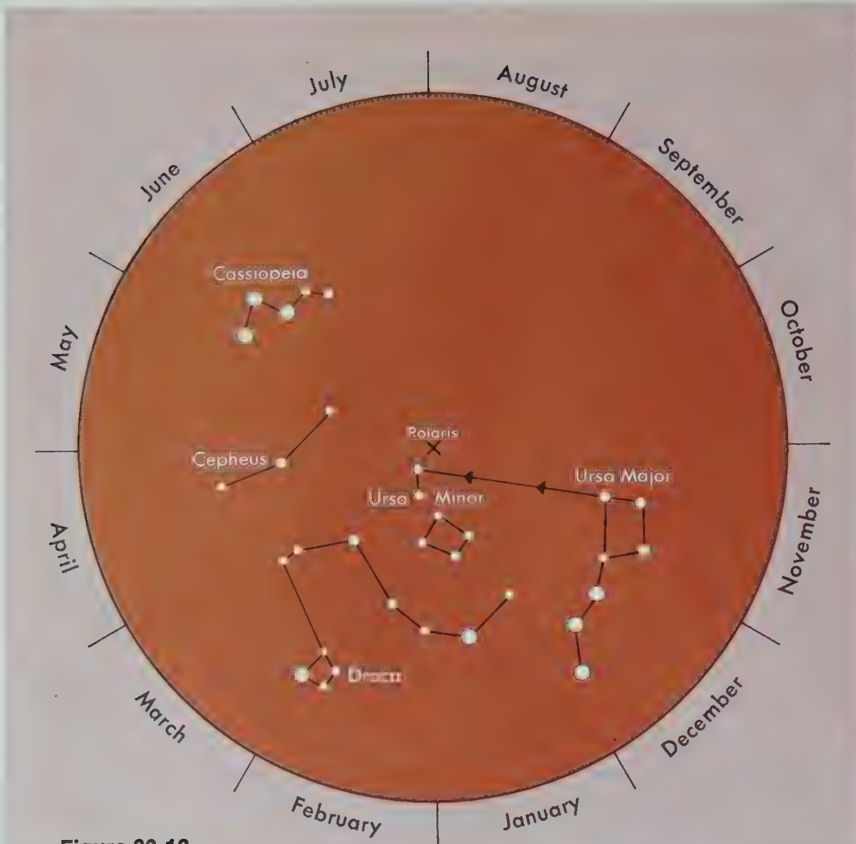

Figure 23-13.

EXPERIMENT. On a piece of drawing paper 10 inches square, draw a circle with a diameter of 8 in. Put an X in the center of the circle to indicate the North Star, Polaris. Divide the circumference of the circle into twelve equal sections and label the sections for the months of the year in sequence. Put thirty dots along each arc to represent the days of the month.

Go outside just after dark on a clear, moonless night. Be sure to make your observations at the same time every night. Face north and hold the diagram up with the dot which represents the date of your observation at the top of the chart. Note the positions of Ursa Major *and* Ursa Minor *and put them on the diagram. Be sure to locate them in relation to Polaris. Add* Cassiopeia *(kas ee a pee′a),* Cepheus *(see′feus), and* Draco *(drae′koh). In two weeks, compare your calendar and the star positions to see if the constellations are correct for that date. Remember, the correct date is always at the top of the chart as you face north. If you did not know today's date, how could you use a star calendar to determine the approximate date? Could you use this star chart in the Southern Hemisphere? Explain your answer.*

23:3 Galaxies

Galaxies are very large groups that contain billons of stars. Galaxies continue outward in space in all directions as far as man can see with modern telescopes. They are so far away that they have not always been recognized as groups of stars. When the 100-inch telescope was installed in 1920 at Mount Wilson, California, stars could be seen in regions of the sky that formerly had appeared as faintly glowing spots call *nebulae.* In 1924 Edwin Hubble, a California astronomer, examined certain gaseous nebulae which were thought to be within our Galaxy. He was able to see stars in many of these areas. By noting the presence of Cepheids, Hubble was able to show that the nebulae were outside our Galaxy. He reasoned that these extragalactic nebulae were star systems similar to our Galaxy and that such galaxies continued to the visible limits of the universe. Hubble estimated the universe to extend outward approximately one billion light years. Today, most astronomers estimate the visible limits of the universe to be more than ten billion light years away.

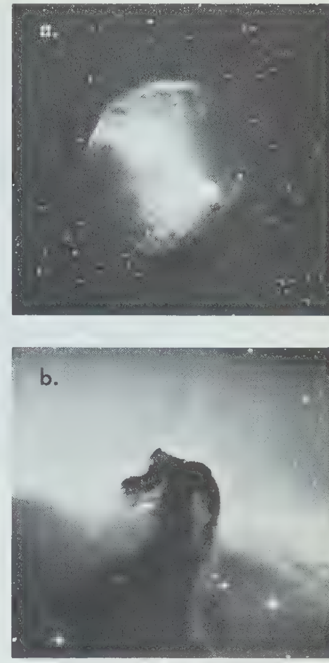

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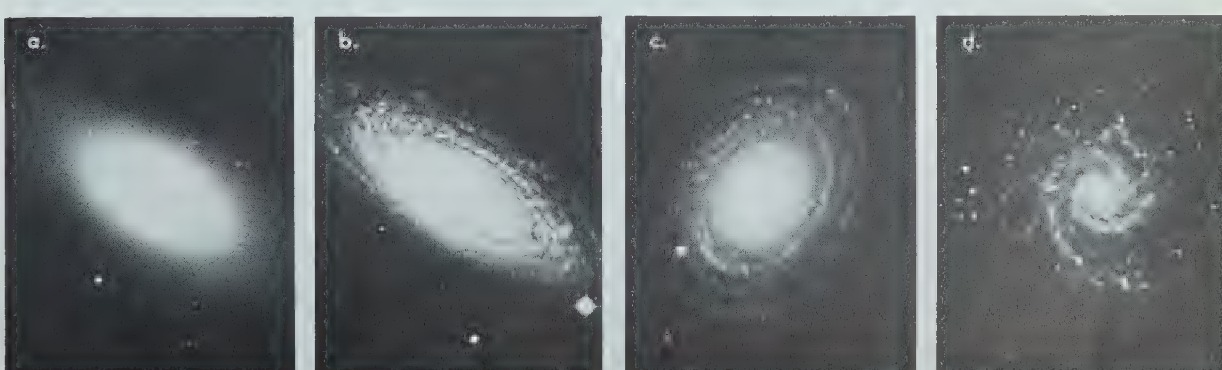
Figure 23-14. (a.) Dumbell Nebula in Vulpecula ejects gases at a relatively low velocity. (b.) Horsehead Nebula in Orion is a large mass of interstellar gas and dust that obscures the stars behind it.

PROBLEM

Our nearest star, other than the sun, is 4.3 light years away from earth. Calculate this distance in miles.

Galaxies have been classified according to their appearance. **Irregular galaxies,** as their name implies, have irregular boundaries. They contain an abundance of gas and dust and some of them appear to be developing spiral arms. Gases are somewhat more concentrated in these developing arms which seem to be rotating around a center. Most stars in irregular

Figure 23-15. Normal spiral galaxies representing evolutionary stages from the young tightly wound SO type (a.) through the barred spirals of (b.) and (c.) to the loosely wound older type Sc (d.).



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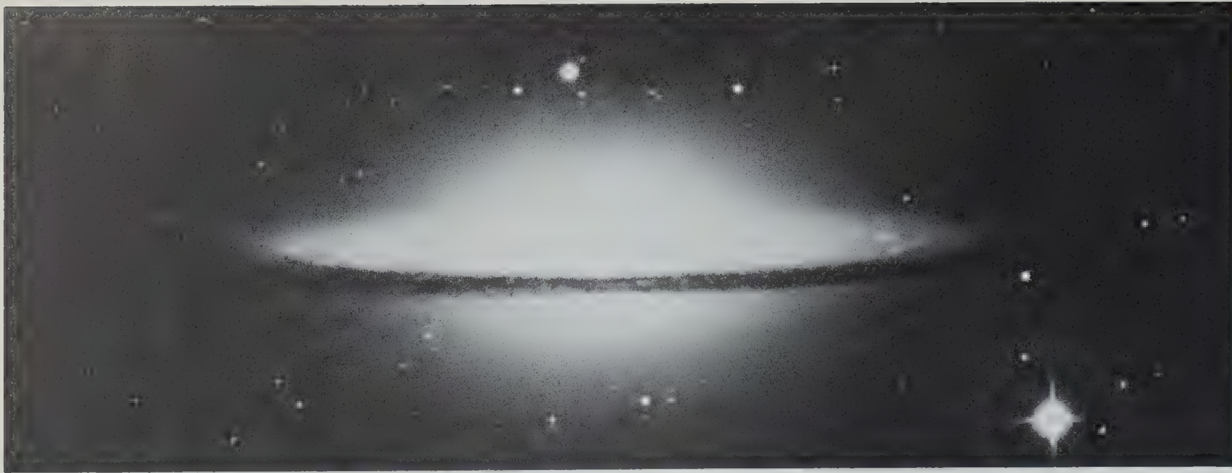


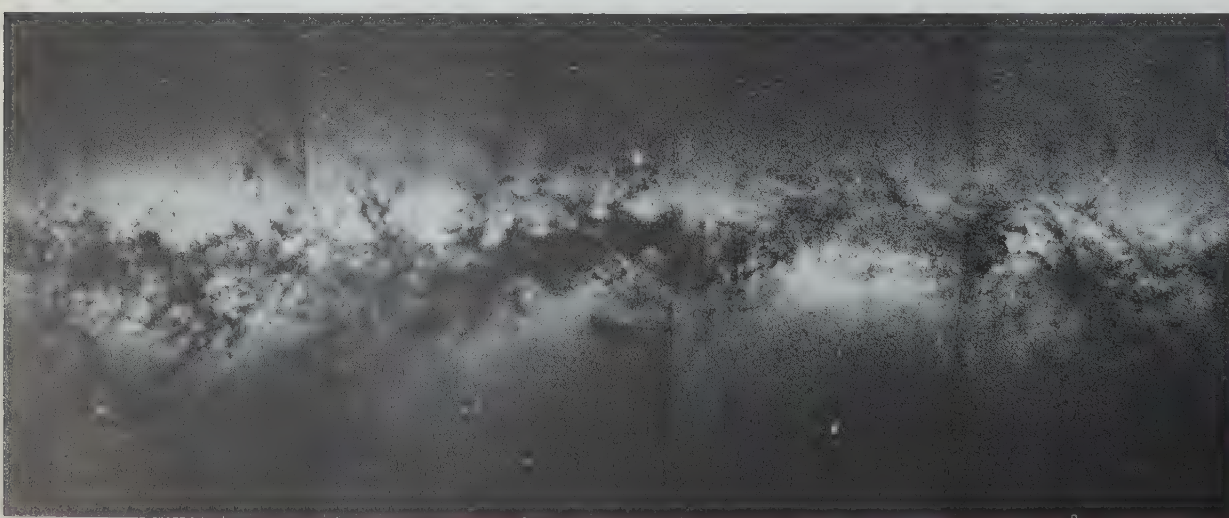
Mount Wilson and Palomar Observatories

Figure 23-16. Spiral galaxy in Virgo as seen on edge.

galaxies appear to be large and probably are in an early stage of stellar evolution. **Spiral galaxies** consist of one or more spiral arms that rotate around a distinct, relatively dense nucleus. Stars in the central hub are probably older than stars in the spiral arms, which contain great quantities of cosmic dust and gas. Possibly these concentrations of cosmic matter have not yet been formed into true stars. **Elliptical galaxies** are symmetrical, ranging from spheres to flattened ellipsoids or disks. Such galaxies contain little dust and gas, possibly because these cosmic materials already have been formed into stars.

The **Milky Way**, which appears in the sky as a band of indistinct light, is the galaxy to which our solar system belongs. The Milky Way is a spiral galaxy, with a diameter of about 80,000 light years. It contains approximately 100 billion to 200 billion stars with almost all of them at least 100 light years distant

Figure 23-17. Mosaic of the Milky Way from Sagittarius to Cassiopeia.



Mount Wilson and Palomar Observatories

from earth. Light which reaches earth from the star *Alpha Centauri* (al′fa•sen tawr′ee) left there 4.3 light years ago. Yet Alpha Centauri is the nearest star to our solar system! Our sun is about ⅔ of the way between the center and outer edge of our Galaxy. Although the sun travels at a rate of approximately 500,000 mi/hr and carries the rest of the solar system along with it, it requires about 250 million earth years for the sun and its planets to complete a revolution of our Galaxy.

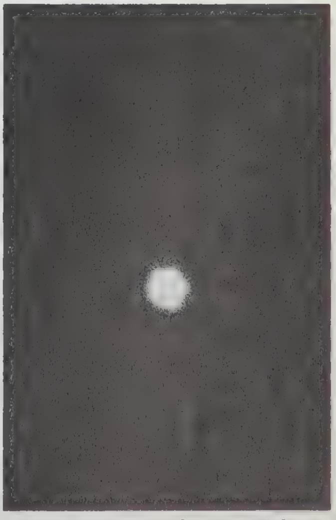
Revolution of the Milky Way by the sun requires 250 million years.

Two nearby galaxies are known as the *Magellanic* (maj e lan′ik) *Clouds*. The Large Magellanic Cloud, the exterior galaxy closest to us, is at a distance of 160,000 light years. The Small Magellanic Cloud is at a distance of 180,000 light years. *Andromeda* (an drahm′ed a) *Galaxy*, about 2,200,000 light years away, is the most distant galaxy visible to the unaided eye. It is a spiral galaxy of a size and shape similar to our Galaxy.

23:4 Quasars

Astronomers have been familiar with stars for centuries and with the concept of galaxies for less than 50 years. Recently, a different type of celestial body, called *quasars*, has become important to scientists. **Quasar** (kwae′sar) is a name coined by Dr. H. Y. Chiu of Goddard Institute for Space Studies as a substitute for the term "*quas*i stell*ar* radio sources." Quasars are powerful sources of radio energy. They have been called "quasi stellar" because they seem to be starlike objects, but actually they do not appear to be stars. Quasars are celestial objects different from anything known previously. Quasars were discovered in March, 1963, when radio astronomers in Australia and California pinpointed the location of five sources of radio noise in space. These five locations were photographed from the Mount Wilson and Palomar Observatories. Faint, starlike objects appeared on the photographic plates at the locations determined by radio telescopes. Except for the sun, these were the first so-called "radio stars" to be photographed and identified as localized radio sources.

Figure 23-18. In 1961, Allan R. Sandage discovered 3 C 48, the first star-like object found at the location of a strong well-known radio source.



Mount Wilson and Palomar Observatories

Astronomers at Mount Wilson and Palomar Observatories recorded the light spectrum from two of the quasars. Wavelengths of light emitted by hydrogen were recognized, but they were at longer wavelengths than similar lines emitted in earth laboratories. The increase in wavelength toward the red part of the light spectrum is known as the **red shift.** Astronomers showed that red shifts of galaxies increase as their distance increases or, in other words, the faster the motion, the more the galaxies shift.

Apparent red shift of quasars suggests that they are the most distant celestial objects, according to some astronomers.

Quasars are small compared to galaxies but produce vast amounts of energy.

Some astronomers believe quasars are within one hundred million light years of earth but moving away at enormous speed.

The faster a galaxy moves away from earth, from the solar system, or from our Galaxy, the more distant the galaxy is thought to be. Astronomers applied this knowledge to interpret the behavior of quasars and found the red shifts to be greater than the shift for the visible galaxies. Such large red shifts seem to indicate that quasars are more distant than the most distant galaxies.

If quasars are the most distant objects in the universe as the red shift seems to indicate, they must be extremely bright. Quasar light appears faint on photographic plates because quasars are so distant. But they must emit many times more light than the brightest galaxies. Typical galaxies may contain 100 billion stars. Astronomers and physicists are attempting to understand how an object can outshine 100 billion stars.

But not all astronomers believe that quasars are as distant as their red shifts suggest. These astronomers account for the almost unbelievable brightness and the release of enormous amounts of energy by assuming that quasars are less than one hundred million light years from earth. In this theory, quasars are assumed to be nearby objects which possess enormous speed. A red shift of 200 percent implies a speed of 150,000 mi/sec which is over 80 percent of the speed of light. The main difficulty with this theory is how to account for the high rate of speed. Release of energy can be accounted for by familiar processes within stars.

One idea to account for the speed of quasars suggests that they have been hurled into space during explosions within radio galaxies. An idea to account for brightness is that quasars come from superstars and collapsed superstars account for the radio energy. Many other explanations have been proposed in an attempt to account for quasars. Some astronomers suggest that they were formed during star-collisions, births of galaxies, or even the births of miniature universes. But the problem of the red shift is still unsolved.

To many astronomers, the red shifts of the quasars indicate that quasars are the most distant and the brightest objects in the universe. But quasars are small compared to galaxies. Quasars occupy volumes measuring 3 light years or less in diameter. Typical galaxies occupy space measured in tens of thousands of light years. A most difficult problem is to account for the production of such vast amounts of energy from such small volumes. Perhaps new theories for the generation of energy

may be needed to explain the power sources of quasars. Answers to the quasar mystery may change ideas about matter, gravity, energy, and other basic concepts of physics. For those reasons, astro-physicists study quasars intently and have measured red shifts for about half of the known quasars.

23:5 *Optical Telescopes*

Modern astronomers have learned about the chemical composition and physical state of celestial bodies and have been able to draw certain conclusions about the motions of stars, galaxies, and quasars because of the development of astronomical measuring devices and methods.

The earliest astronomical device was the **quadrant** (kwahd′ rant), or quarter circle, used to measure the altitude of stars. A quadrant consists of an arc divided into 90°. A simple sighting index is used to measure the position of a celestial body above the horizon. Galileo developed an "optik tube," a type of telescope called a **refractor** or **refracting telescope.** It has a large front lens, or *objective*, and a second lens, called the *ocular*, which forms the eyepiece at the opposite end of the tube. The objective lens collects light and bends or refracts light rays toward a focal point. A *focal point* is the position where a small image of an object is formed. *Focal length* is the distance between the focal point and the lens. Ocular lenses magnify an image formed by the objective. Image size is proportional to the focal length of the objective and the ocular lens.

Refracting telescopes are usually long and rather unwieldy. Astronomical refracting telescopes are similar to spyglasses,

Figure 23-19. By sighting through the eyepiece of this astronomical quadrant, a star's altitude could be determined.

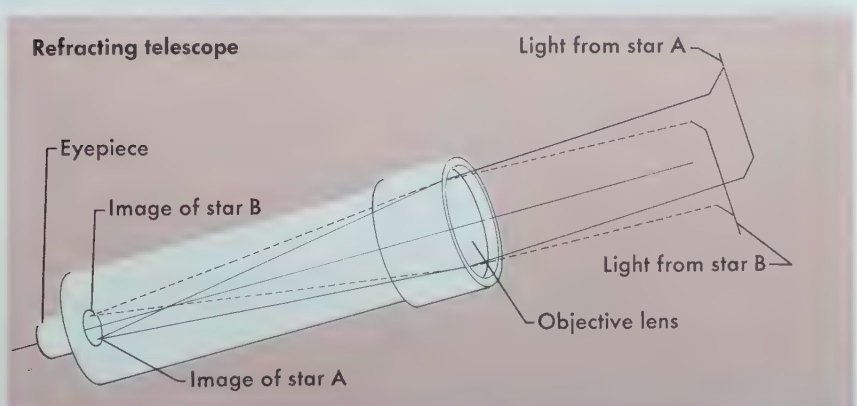


Figure 23-20. Starlight that enters the objective lens of a refracting telescope is observed through the eyepiece.

Problems associated with producing flawless glass of large area limits the size of refracting telescope lenses.

except that in the spyglass both the objective and ocular lenses are mounted in sliding metal tubes. Sliding tubes make it possible to adjust the position of an image to the focal length of each lens. Also, spyglasses are usually fitted with an additional lens which turns the image right side up for the viewer. In astronomical telescopes, a star's image is inverted. But stars appear much the same whether or not they are upside down, and the extra lens is omitted. Presence of the extra lens would reduce efficiency of the telescope by causing a loss of light.

Refracting telescopes used by amateur astronomers are limited in size. Usually the diameter of the objective lens is 3 in. or less and the tube length is about 5 ft. Galileo's telescope had a paper tube 4 ft long and an objective with a 2 in. diameter. Magnification with Galileo's telescope was 32 times, but its field of view was small. Yerkes Observatory in Wisconsin has the largest refractor telescope. Its focal length is 60 ft and its objective has a 40 in. diameter.

Size of a refractor telescope's objective is limited by the difficulty of preparing bubble-free optical glass of large area. Costs rise rapidly as lens size increases. Grinding and polishing a large lens is difficult and expensive, and there is a practical limit to the diameter of a lens. But large diameter lenses are desirable because they collect more light than small lenses and collection of light is the basic function of the telescope. Amount of light collected depends on the area of the objective. As the amount of collected light increases, stars that are too faint or too distant to be seen with smaller telescopes can be observed and photographed.

Mirrors do not require flawless glass, and may be larger than lenses.

To overcome the size limitation of an objective lens, *concave mirrors* are used. Mirrors are easier and cheaper to produce than lenses because mirrors do not require bubble-free glass. An aluminum reflective coating on the front surface of a mirror prevents light from passing through the glass. Bubbles and flaws within the glass are relatively unimportant if the light does not pass through it. Telescopes that use concave mirrors instead of lenses are called **reflector telescopes.** Sir Isaac Newton invented the reflector telescope in 1668.

In a reflector telescope, a concave mirror collects light from a star and produces a small image at the focal point of the mirror. In most reflectors, a mirror, tilted at a 45° angle to the axis of the concave mirror, reflects the image to the eyepiece. The eyepiece, which is mounted on the side of the tube or framework housing the concave mirror, magnifies the image.

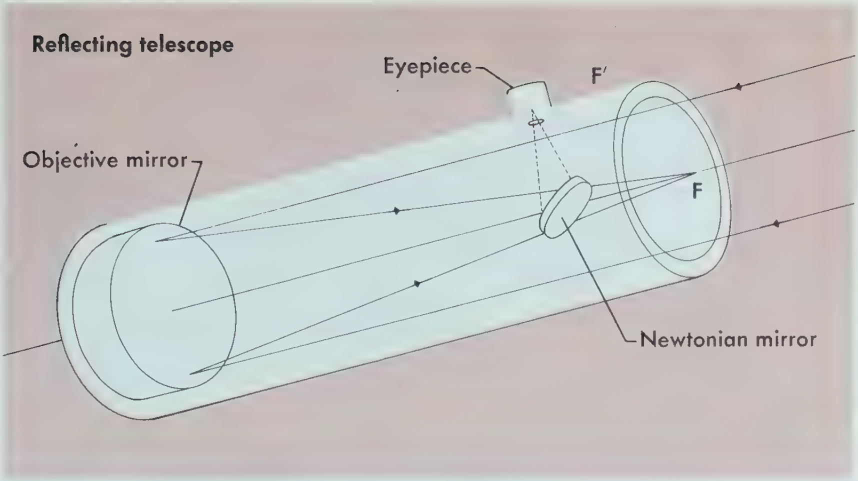


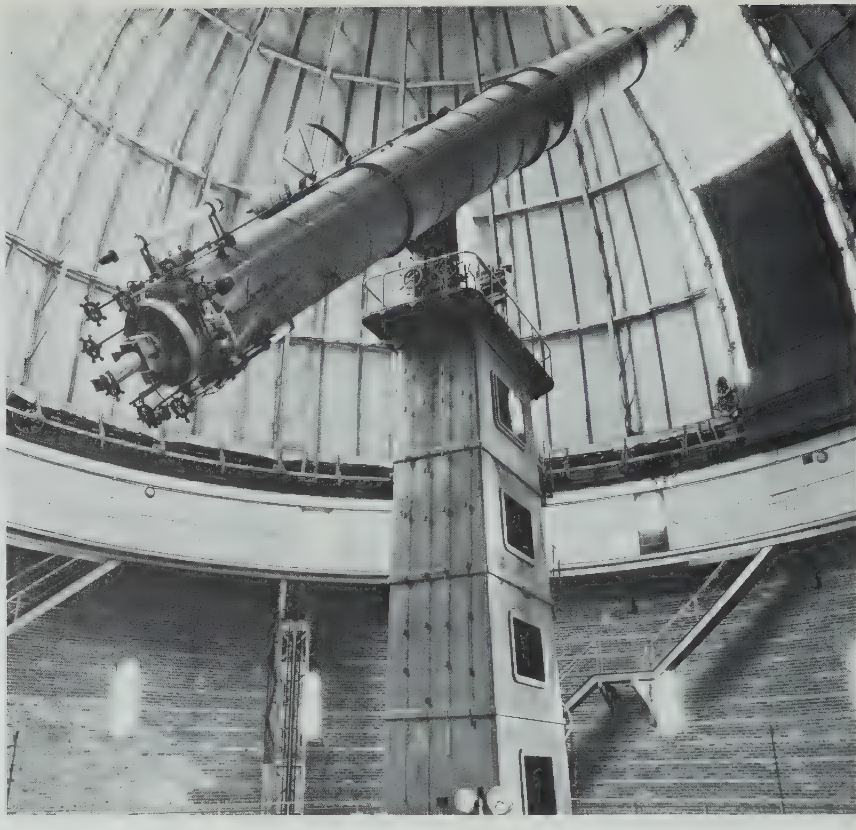
Figure 23-21. In the reflecting telescope, light is reflected from objective to eyepiece.

Reflector mirrors are cheaper and easier to build than a lens of equal diameter. Large mirrors are ground from optical glass which has been cast in a mold. Cooling is carefully controlled at a slow rate to avoid internal strain. Palomar Mountain Observatory has the world's largest optical telescope. Its mirror has a diameter of 200 in. Cooling of the cast mirror blank continued for almost one and a half years after the molten glass was poured into the mold.

Mount Wilson and Palomar Observatories

Figure 23-22. Dome of the 200-inch Hale telescope, largest in the world, at Mount Wilson and Palomar Observatories.

Figure 23-23. Yerkes Observatory, Wisconsin, has a 40-inch refracting telescope, the largest refracting telescope in the world.



Yerkes Observatory Photograph

Problem

Yerkes Observatory has the world's largest refracting telescope with a lens diameter of 40 in. Palomar Mountain Observatory has the world's largest reflecting telescope with a mirror diameter of 200 in. Which telescope collects the most light? How much more light is collected?

Movement of a telescope on the polar axis compensates for earth's rotation.

Telescopes must be moveable in order to view different areas of the sky. Furthermore, through a stationary telescope a star would appear to move westward and, eventually, would move beyond the field of view. This apparent westward movement of stars results from the earth's rotation. To cancel the effect of earth's rotation, a telescope is mounted so that it runs on an axis called the *polar axis*. The polar axis of a telescope is parallel to the earth's axis and its ends point toward the celestial poles. (Section 21:3.) Usually a clock or motor drive turns the telescope on its polar axis at the same rate of speed as the rotation of the earth, but in the opposite direction. A telescope is mounted at an angle with a horizontal plane equal to the latitude of the observatory.

Second axis of the telescope, called the *declination axis*, is perpendicular to the polar axis. As a telescope turns on the declination axis, it moves northward or southward. Together the polar axis and declination axis make it possible to aim a telescope at any point in the sky. This type of telescopic mounting is known as an *equatorial mounting*.

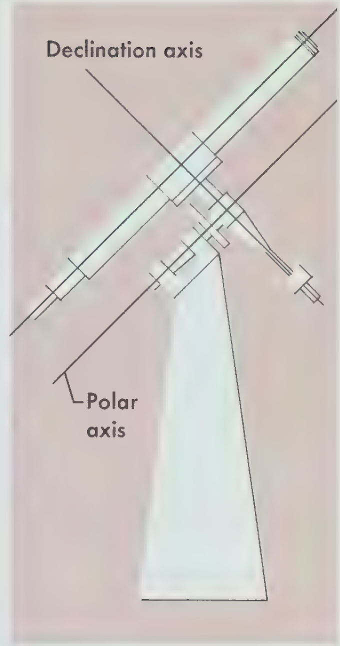


Figure 23-24. The equatorial mounting permits the telescope to point to any spot in the sky and to compensate for rotation of the earth.

Astronomers use telescopes to study celestial objects through both visual observation and photography. Photography of the night sky has become increasingly common since 1850. Reflector telescopes are adapted to camera work better than refractor telescopes because refractor lenses cannot transmit ultraviolet radiation, an important consideration in astronomical photography. Reflective coatings of mirrors have been improved to the point where photography of the ultraviolet range of the light spectrum is possible. Photographic plates are especially sensitive to the blue to ultraviolet part of the spectrum. All major observatories now have cameras or plateholders attached to their telescopes.

Cameras have many advantages over visual observation. Pictures actually may record light which the eye cannot see. Long time exposures allow the effect of faint light rays to accumulate until light becomes visible on a developed photographic plate. Another advantage of plates is the permanent record which they provide. From plates, measurements of stars may be determined and rechecked at a later date if desired. With the help of a microscope, distance between stars can be measured accurately and their positions determined on a photographic plate. Measurements of similar accuracy would be almost impossible with direct viewing alone. Furthermore, special processes permit computation of a star's distance from earth. Combined camera and telescopic observations have produced a great expansion in astronomical knowledge.

New methods and types of cameras continue to be adapted to telescopic work. For example, **television cameras** may be attached to the eyepiece of a telescope to brighten the star's image as it appears on a television screen. Improved pictures can be made from this bright image on the screen. Still another improvement in photographic equipment is the **Schmidt camera.** This camera has been useful in discovering many new stars. Before 1930, it was impossible to photograph large areas of the sky successfully. Blurred images always appeared at the edge of the field of view. In 1930, Bernhard Schmidt, a German astronomer, devised a specially shaped glass plate which he placed

Schmidt's camera improved the quality of wide-area photographs.

in front of the reflector mirror. This type of plate prevents the formation of the blurred image formerly associated with wide-angle reflector telescopic photographs. Palomar Mountain Observatory now uses a 48-in. Schmidt camera.

Another device that is useful to the astronomer is the **photometer** (foh tahm′e ter). Photometers measure the intensity of light received from celestial objects. In 1725, brightness of sun and moon was compared to candlelight. But after 1830, several devices for measuring light intensity became available. One early photometer used an electric light bulb to create a star-like image. Brightness of this image could be adjusted to match the brightness of stars or planets under observation. This early instrument measured brightness in terms of the light bulb and depended upon visual comparison. Today, visual comparison is seldom used. Instead, highly accurate photometers which depend on photoelectric methods of measurement are used.

Actual photographs of celestial bodies are of great interest to astronomers. From a scientific viewpoint, perhaps even more information is obtained from photographs of the spectra of stars.

Spectroscopes are instruments that separate visible light into various wavelengths or frequencies by means of either glass prisms or ruled gratings. Ruled gratings are pieces of glass or highly polished metal on which a large number of closely spaced, fine parallel lines have been drawn. Small spectroscopes may have glass prisms, glass gratings, or aluminum-coated glass. Large spectroscopes usually have metal gratings. Lines are drawn by a ruling instrument which has a diamond point. Standard grating spacing varies from 5,000 to 30,000 lines/in.

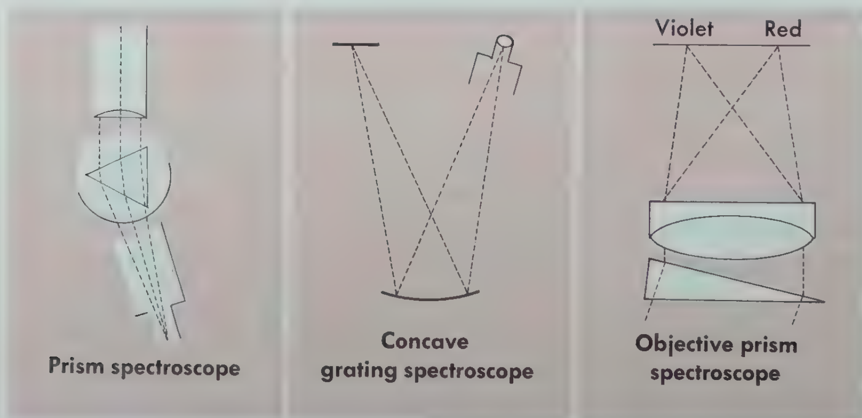


Figure 23-25. The spectroscope disperses light by prism or grating in order to study the stellar spectrum.

The *slit*, or opening through which light is admitted to the spectroscope, determines the quality of the spectrum obtained. Usually the width of the slit can be adjusted to between 1.0 mm and 0.005 mm. Lines seen in the spectrum are single color images of the slit. Although slits are used with most prism and ruled grating spectroscopes, slitless spectroscopes have been developed for special kinds of work with stars.

Spectroscopes in which cameras or plate holders replace the eyepiece are called **spectrographs.** Spectrographs are used to photograph the spectra of stars. These photographs are known as **spectrograms.**

Spectrographs are spectroscopes which use cameras in place of eyepieces.

Spectrograms of stars usually are compared with the spectrum of iron. The iron spectrum is used as a standard for comparison because iron produces spectral lines through the entire visible light range. A standard for comparison aids astronomers in recognizing the presence of the red shift for stars or galaxies. Usually a star's spectrogram has iron's spectrum photographed first and placed at the top of the photograph. Next the star's spectrum is photographed and placed in the middle. Then another photograph of iron's spectrum is placed at the bottom. Before and after pictures are taken to check changes in conditions of temperature or air movements which may have distorted the star's spectrum during photographing. Comparison of the spectrum allows any necessary corrections for the changed conditions to be made. Spectrum lines of a star are identified by measuring wavelengths with the aid of a microscope. Astronomers also use specially designed measuring instruments which take readings that can be repeated to within 0.002 mm.

A star's spectrum is compared to the spectrum of iron as a standard.

Heat sensitive spectrographs have been designed to measure the infrared spectrum which is of longer wavelength than the red end of the visible spectrum. A sensitive heat detector called a **radiometer** is placed at the focal point of a reflector telescope. Radiometers measure the amount of heat produced by the incoming radiant energy from a celestial object. Various types of radiometers may be used, including *bolometers*, *vacuum thermocouples*, or *thermopiles*. These devices convert radiant energy to electrical output which is amplified and automatically recorded. At the same time, the celestial body is being scanned by the telescope. Infrared spectrograms have been used in the identification of gases in planetary atmospheres. They also have been used to measure the temperature of planets and stars.

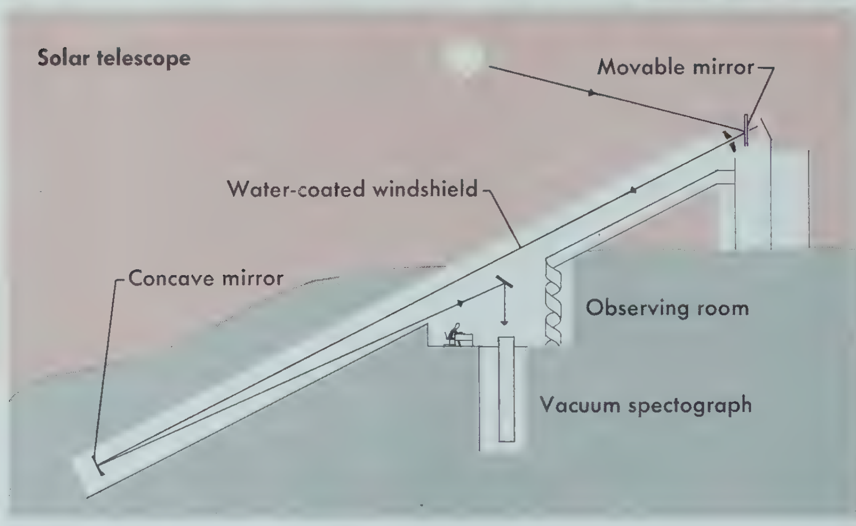
Radiometers are used with reflector telescopes to study the infrared portion of a star's spectrum.

Infrared spectrograms are used in identification of planetary atmospheric gases and to measure temperatures of planets and stars.

Figure 23-26. Most of the large solar telescope at Kitt Peak, Arizona, is beneath the surface of the earth.


Kitt Peak National Observatory

Figure 23-27. The length of the solar telescope at Kitt Peak is 500 feet. This great length reduces the intensity of sunlight so it can be studied.



Some astronomical devices have been designed especially for studying the sun, the star closest to earth. Due to the high intensity of sunlight, great dispersion or spreading of light is possible. By comparing the sun's spectrum with the standard laboratory spectra of known elements, 67 elements have been identified in the sun.

At Mount Wilson Observatory, a specially designed 150-ft tower has been constructed for the study of the sun. A mirror is placed at the top of the tower in order to avoid air movements caused by the sun's heating of the ground surface. A laboratory is located below ground level where uniform temperature is maintained. The mirror system transmits a beam of parallel sunlight through an insulated tube from the top of the tower to the laboratory. These precautions are taken to avoid the effect of air currents which might distort the sun's spectrum.

Another instrument called the **spectroheliograph** is used to photograph the sun in the light of a single wavelength. Spectroheliographs are similar to spectrographs except that the spectroheliograph has two slits instead of one. The second slit, located in front of the photographic plate, allows light from only one spectral line to strike the photographic plate. Thus, the sun can be photographed with the light of elements such as calcium, potassium, or hydrogen in the sun's surface. Distribution and movement of these elements in the sun can be recorded by a series of pictures taken at different times.

Spectroheliographs make it possible to photograph the sun in the light of a single element.

Coronographs are instruments which permit photographing of the sun's corona, solar prominences, and chromosphere. By creating an artificial eclipse of the photosphere, the coronograph makes it possible to take spectacular motion pictures, particularly of the prominences.

Coronographs act as artificial eclipses to eliminate light from the photosphere in photographs of the sun.

23:6 *Radio Astronomy*

Radio astronomy began in 1932 when Karl Jensky of Bell Telephone Laboratories discovered that radio wavelengths of 14.7 m were coming from the Milky Way. In 1939, Grote Reber, an amateur radio operator at Wheaton, Illinois, built the first radio telescope. With it, he mapped radio waves of 1.85 m coming from our Galaxy.

Radio astronomy is a study of radio waves originating from celestial bodies.

Radio wavelengths from outer space range from a few millimeters to 30 meters. Radio waves pass easily through the dust of space and the clouds of earth's atmosphere because radio wavelengths are much longer than light wavelengths. By blocking out light waves, dust in outer space hides much of the universe from view. Also, clouds in earth's atmosphere and turbulent air movements make visual observations and photography of the sky difficult. But radio observations can be conducted night and day without these interferences.

Unlike visible waves, many radio waves are not blocked out by cosmic dust and gas.

Some radio sources which are too far away to be seen or photographed by optical telescopes have been detected by radio astronomy. Radio astronomy is the only way in which knowledge of the invisible and most distant parts of our universe can be obtained at present. Two types of radio waves—thermal and non-thermal—reach earth from outer space. Like light, thermal radiation is generated by hot particles or objects. According to one theory, non-thermal radio waves result from high speed electrons which react with a magnetic field.

Figure 23-28. This radio telescope at Goldstone, California, a part of the Deep Space Network, is engaged in collecting radio signals from outer space.

Radio telescopes have directional antennas which collect radio waves.

Radio telescopes consist of a *directional antenna* and a highly sensitive *radio receiver*. Receivers are used to detect and amplify radio waves. They also select wavelengths within narrow limits or bands. Receivers are connected to a recording meter which charts the power of waves collected by the antenna as it probes the sky. Some noise is created by the receiver. Sensitivity, or receiver efficiency, depends on the ratio between power of incoming radio waves and noise created within the receiver.

Dipoles consist of two insulated metal rods placed at the focal point of a reflector mirror.

Antennas of radio telescopes are directional, or narrow beam, types which collect radio waves in the way that optical telescopes collect light waves. Antennas collect radio waves from a desired direction and focus them for the receiver. Although directional antennas have many different designs, each antenna has a dipole. *Dipoles* are directional antennas which consist of two insulated metal rods or wires placed in line. Total length of the rods is less than one-half the wavelength of radiation which is to be measured by the radio telescope. Dipoles receive wavelengths best coming from a direction perpendicular to the rods or wires. When placed at the focal point of a concave metal reflector of short focal length, dipoles are highly directional and efficient collectors of radio waves.

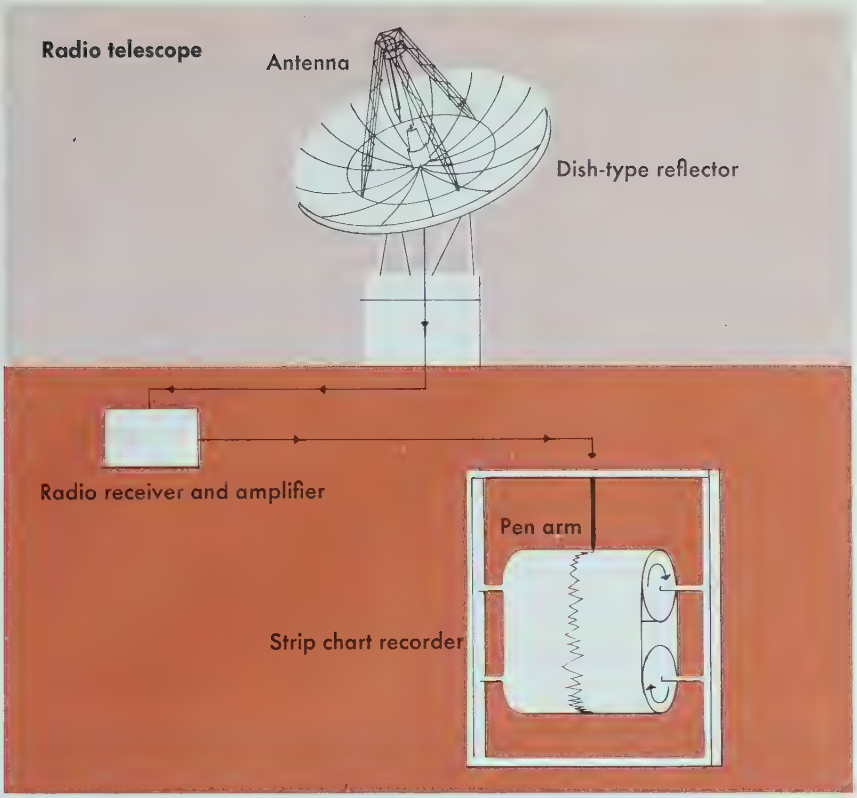


Figure 23-29. **The radio telescope consists of a dish for concentrating radio waves on the antenna, an amplifier, and a recorder which transcribes the signals.**

Concave metal reflectors, often called *dishes*, are similar to reflectors of optical telescopes. In order to collect radio waves of many wavelengths, and particularly the long wavelengths, reflectors must have a large diameter. Solid metal reflectors are costly and difficult to build, but reflectors need not be of solid metal. Instead, metal mesh or screen wire may be used, which reduces the weight and the area of the reflector exposed to wind pressure. Hole size in the mesh needs to be at least as small as $\frac{1}{5}$ of the wavelength to be measured by the telescope. Like optical telescopes, radio telescopes need to be built so they can be aimed toward different areas of the sky. But as size increases, it becomes more and more difficult to construct a reflector that is steerable. The Jodrell Bank, England, radio telescope has a steerable dish with a 250-ft diameter. There are other large, steerable radio telescopes in the United States whose diameter ranges from about 20 ft to more than 200 ft. The 1,000-ft diameter dish of the telescope at Arecibo, Puerto Rico, is not steerable.

Most radio telescope reflectors are made of metal mesh to reduce weight and area exposed to wind pressure.

Not all radio telescopes are steerable. The larger the reflector diameter, the more difficult it is to construct.

Compared to optical telescopes, radio telescopes have less resolving power, or capability for observing fine details. *Resolving power* is a measure of an instrument's ability to distinguish

Radio telescopes do not distinguish between energy sources as efficiently as optical telescopes.

between separate sources of radiation. Resolving power is measured in degrees, minutes, or seconds of arc. Radio telescopes can separate only sources of power that are minutes, or even degrees apart. But Palomar's 200-in. reflector telescope can identify sources of light that are only a few hundredths of a second apart. The larger the dish of a radio telescope, the greater is its resolving power. But unlimited increase in dish size becomes impractical.

Two or more widely separated antennas attached to the same receiver improve resolution or resolving power of radio telescopes. These devices are called **interferometers.**

A radio **interferometer** is a device used to improve the resolving power of the radio telescope. An interferometer is a multiple-element radio telescope in which two or more antennas, separated by several thousand feet, are connected to the same radio receiver. Reception of radio waves has been improved by the interferometer and the resolving power increased to one minute of arc or less. Astronomers at the University of Manchester, Australia, use antennas that are separated about 75 mi or 61,000 wavelengths to increase their resolving power to one second of arc. Separate dishes attached to the same receiver produce the effect of a single dish of huge proportions. The importance of radio interferometers may be understood from the fact that quasars were first located through their use. Later, quasars were confirmed by photographs.

Radio spectroscopy uses the hydrogen radio emission wavelength to measure velocity of radio sources.

Radio spectroscopy is still another tool which astronomers have used since 1951. Scientists found that hydrogen emits a radio wavelength of 21 cm. It is possible to measure the velocity of radio sources of quasars and radio galaxies using measurements of the Doppler shift of hydrogen lines in radio spectra. Another contribution through use of radio spectroscopy was the tracing of the spiral arms of the Milky Way Galaxy.

Radar, or "*ra*dio *d*etecting *a*nd *r*anging," refers to the detecting of an object beyond the range of visibility and the determination of the object's distance or range from the radar station. Detection of the object is accomplished through the use of pulses of radio waves, or radar waves.

Radar wavelengths are not defined rigidly, but range from microwaves, which usually are considered to be wavelengths of 0.1 cm to 10 cm, up to wavelengths of 10 meters.

Radar waves are pulses sent out from a transmitter and reflected to a receiver placed near the transmitter.

Radar measures the travel time of a radio pulse sent out from a transmitter and reflected from a target to a receiver. Like an echo, a small fraction of energy returns to the receiver which usually is located with the transmitter. (Section 11:4.) Travel time of radar waves from transmitter to receiver is a

measure of the distance to the reflecting object and back to the transmitter. Travel time can be measured to about a millionth of a second.

Although radar originally was designed to detect objects on or near earth, astronomers now make use of radar waves for detecting celestial objects. (Section 21:5.) Microwaves are particularly useful in studying the planets. Radar is being used to determine distances to planets, rate and direction of rotation, and rough or smooth character of planetary surfaces.

Radar waves are used to measure distances, rotation, and surface characteristics of the planets.

Galileo with his telescope made observations that opened an era of research and scientific understanding. Many scientists have followed in his footsteps or found new paths to travel in attempting to solve problems concerning the universe. Each new instrument and each new measurement opens further possibilities of knowledge, but it also brings new questions. Pursuit of scientific knowledge and understanding remains a never-ending quest.

Arecibo Observatory, Puerto Rico

Figure 23-30. Beginning with visual observation of his environment, man has progressed to the instruments of radio astronomy like this one at Arecibo, Puerto Rico, by which he probes the invisible and most distant parts of his universe.

MAIN IDEAS

1. Different forms of radiant energy may be recognized by their wavelengths or frequencies. An electromagnetic spectrum includes all radiant energy forms and is arranged according to wavelengths or frequencies. Visible light makes up a small portion of the electromagnetic spectrum. Other forms of radiant energy include cosmic waves, gamma rays, X rays, ultraviolet rays, infrared rays, and radio waves. Knowledge about space depends upon a study of radiant energy.
2. Stars emit continuous spectra crossed by dark absorption lines. From the spectra, astronomers determine which elements are present in a star and which wavelengths or frequencies have been absorbed by the outer gases of the star. Shifting of spectral lines indicates whether stars are approaching the earth (shift to the violet end of the spectrum) or receding from earth (shift toward the red end of the spectrum).
3. Stars are formed from interstellar matter which condenses and eventually reaches temperatures at which transmutation of hydrogen to helium occurs. Stars probably evolve from condensing masses of cosmic material,which achieve equilibrium when radiant energy is released at the surface at the same rate it is produced within the star's interior. Stars in equilibrium are known as main sequence stars. When hydrogen of the core is consumed, the core collapses and transmutation of hydrogen occurs in the outer envelope. At this stage, stars may become novae or supernovae. Last stage in stellar evolution is the white dwarf, a star in which almost all transmutation of hydrogen to helium has been completed.
4. Cepheids are stars that have periodically increasing brightness followed by decreasing brightness. The period of a Cepheid is related to its absolute magnitude and can be used to calculate a star's distance from earth.
5. Galaxies contain billions of stars. Galaxies in early, middle, and late stages of stellar evolution are called irregular, spiral, and elliptical, respectively. Irregular galaxies have abundant cosmic dust and gas; elliptical galaxies have very little cosmic dust and gas.

6. Our Galaxy is the Milky Way, a spiral galaxy containing over 100 billion stars and revolving around a central mass of stars. This revolution takes our sun about 250 million years to complete.
7. Quasars are starlike objects that emit radio energy and which appear to be moving away from the earth at an exceptionally rapid rate. Astronomers do not agree on their interpretation of why quasars have such small volumes. About 200 quasars have been located and half of them have been interpreted as showing a red shift indicative of recession from earth, solar system, and galaxy.
8. Optical telescopes may be refractor or reflector types. Refractors use lenses; reflectors use mirrors.
9. Spectroscopes and spectrographs are used in study of the visible and near visible spectrum. With radiometers, the infrared portion of the spectrum can be studied.
10. Radio waves originating in cosmic bodies have been studied by means of radio telescopes. This type of telescope uses a concave metal-mesh dish or a broad flat antenna to collect radio waves.
11. Radar waves, as used in astronomy, are pulses sent into space to probe celestial bodies, which reflect the waves to receivers placed near the transmitter. Radar has been useful in studies of the moon and planets.
12. Today's scientists seek new knowledge as did Galileo and Severinus. Each new instrument and each new measurement furthers the never-ending pursuit of scientific knowledge.

VOCABULARY

Write a sentence in which you use correctly each of the following words or terms.

absorption lines	light year	radar
Cepheids	magnitude	red shift
coronograph	objective	spectrum
dipoles	ocular	slit
frequency	photometer	supernovae
galaxies	quasars	wavelength

STUDY QUESTIONS

A. True or False

Determine whether each of the following sentences is true or false. (Do not write in this book.)

1. Galaxies were first recognized as extremely large groups of stars by Hubble.
2. Galaxies extend less than two billion miles into space.
3. Earth is part of an elliptical galaxy.
4. Earth's nearest star, other than the sun, is 4.3 light years away.
5. In main sequence stars, contraction and expansion produce supernovae.
6. Small red dwarfs and red giants are cooler than the sun.
7. Exceptionally bright stars that disappear from view after a period of brightness are called novae or supernovae.
8. White dwarfs are extremely dense.
9. In the electromagnetic spectrum, radiant energy forms are arranged in the order of their wavelengths or frequencies.
10. Stars are formed from clouds of expanding cosmic gas.

B. Multiple Choice

Choose the word or phrase which completes correctly each of the following sentences. (Do not write in this book.)

1. Light travels at the rate of approximately 186,000 (*feet, yards, miles*) per second.
2. The sun is a (*blue, yellow, red*) main sequence star.
3. Stars in which brightness varies in a predictable cycle are (*Cepheids, quasars, supernovae*).
4. Visible forms of radiant energy are (*television waves, X rays, light waves*).
5. The color with the longest wavelength or lowest frequency is (*violet, blue, red*).
6. A star's spectrum is known as a (*separate, color, continuous*) spectrum.
7. Absolute magnitude refers to the brightness of a star (*as seen from earth, at the star's actual distance from earth, at 32.6 light years from earth*).

8. Stars in the last stage of stellar evolution in the main sequence are called (*white dwarfs, red dwarfs, supergiants*).
9. Variable stars include (*Cepheids, main sequence stars, white dwarfs*).
10. Color of a star is determined by a star's (*density, temperature, mass*).

C. Completion

Complete each of the following sentences with a word or phrase which will make the sentence correct. (Do not write in this book.)

1. The earth belongs to the __?__ Galaxy.
2. Galaxies are classified according to their stage of stellar evolution as __?__, __?__, or __?__.
3. The most distant galaxy which is visible to the unaided eye is __?__.
4. Most massive stars with the highest temperatures are of __?__ color.
5. Quasars appear to be __?__ earth, according to most astronomers' interpretation of the red shift data.
6. Crab Nebula is a cloud of expanding gas which is presumed to represent the remains of a __?__.
7. Quasars were located by means of the __?__.
8. A mirror is used in a reflecting telescope instead of a(n) __?__, as is used in a refracting telescope.
9. Pairs of stars of differing brightness which orbit around a common point and block out the light of each other at times are called __?__.
10. Visible light is separated into colors in the following order, from shortest to longest wavelength: __?__, __?__, __?__, __?__, __?__, __?__, __?__.

D. How and Why

1. Why are boundaries of an irregular galaxy so indefinite?
2. Why does the contraction of a nebula cause a rise in temperature?
3. By observing a star, astronomers can estimate its relative temperature. On what basis can they make such estimates?

4. Distinguish between true and apparent brightness.
5. Explain how astronomers have determined that the sun has 67 elements present in its matter.
6. What methods or instruments do astronomers use to study celestial objects that are beyond the range of visibility?
7. What are the advantages of using wire mesh instead of solid metal reflectors on radio telescopes?
8. Suggest methods and instruments that could be used in a study of Venus' atmosphere and to obtain temperatures of Venus' clouds and surface.
9. How do astronomers determine whether a star is approaching, or receding from, the earth?
10. Travel time of a radar pulse sent on a certain date from Chicago to Venus and back to Chicago is 28.67383 min. How far was Venus from Chicago?

INVESTIGATIONS

1. From library research, report on a myth concerning the formation of a constellation. Discuss the naming of constellations. Have the outlines of the constellations changed since their imaginative naming? Explain your answer.
2. What is the difference between astronomy and astrology? Is either a true science? Locate the astrology chart in the daily paper and discuss its contents.

INTERESTING READING

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APPENDICES
GLOSSARY
and
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APPENDIX A
Metric System

The metric system is a convenient, widely-used system of measurement which has the advantage of units based on ten and multiples of ten. It was developed by using the mass of pure water in the shape of a cube. The "cube of water" was a cubic centimeter—a cube one centimeter long on each edge. The mass of the cubic centimeter of water was measured at an exact temperature of 3.98°C and was called one gram (g). Because ten grams is very small (0.3527 ounces), the kilogram (kg) is sometimes used as the standard of mass in the metric system. A kilogram is equal to 1,000 grams (2.2046 pounds).

The unit of length in the metric system is the meter (m). It is equal to 39.37 inches (in.). The unit of volume in the metric system is the liter (l). A liter is the volume of a kilogram (1,000 g) of pure water measured at an exact temperature of 3.98°C. A liter is equal to 1.06 quarts.

TABLE A–1. Frequently Used Metric Units

	LENGTH	
1 centimeter (cm)	=	10 millimeters (mm)
1 meter (m)	=	100 centimeters (cm)
1 kilometer (km)	=	1000 meters (m)
	VOLUME	
1 liter (l)	=	1000 milliliters (ml)
	MASS	
1 gram (g)	=	1000 milligrams (mg)
1 kilogram (kg)	=	1000 grams (g)

TABLE A–2. Metric Unit Prefixes and Their Definitions

kilo—	1,000	$= 10^3$
hecto—	100	$= 10^2$
deka—	10	$= 10$
deci—	0.1	$= 10^{-1}$
centi—	0.01	$= 10^{-2}$
milli—	0.001	$= 10^{-3}$
micro—	0.000001	$= 10^{-6}$

The metric system has been legal in the United States since 1866. Because both metric units and English units are used, it is helpful to know how to convert from one system to the other. The relationships of some metric units and English units are given in Table A–3.

TABLE A–3. Metric-English Equivalents

LENGTH

1 in. = 2.54 cm	1 cm = 0.3937 in.
1 ft = 0.3048 m	1 m = 39.37 in. = 3.2808 ft
1 mi = 1.609 km	1 km = 39,370 in. = 3,280 ft = 0.62137 mi
1 in.^{2} = 6.452 cm^2	1 cm^2 = 0.1550 in.^{2}
1 ft^2 = 0.09290 m^2	1 m^2 = 10.764 ft^2
1 mi^2 = 2.59 km^2	1 km^2 = 0.3861 mi^2

VOLUME

1 in.^{3} = 16.387 cm^3	1 cm^3 = 0.0610 in.^{3}
1 ft^3 = 0.02832 m^3	1 m^3 = 35.315 ft^3
1 mi^3 = 4.1681 km^3	1 km^3 = 0.2399 mi^3
1 qt = 0.946 l	1 l = 1.06 qt

MASS

1 oz = 28.35 g	1 g = 0.0022 lb = 0.0353 oz
1 lb = 453.6 g	1 kg = 2.2 lb = 35.3 oz
1 ft^3 of water = 62.4 lb	1 cm^3 of water = 1 g

APPENDIX B Temperature Scales

The scale of degrees devised by G. D. Fahrenheit is the one used on thermometers for homes. It is called the *Fahrenheit temperature scale.* It is abbreviated as F. The freezing point of pure water at one atmosphere of pressure is assigned a value of thirty-two degrees (32°). The boiling point of pure water at one atmosphere of pressure is assigned a value of two hundred and twelve degrees (212°).

The *centigrade or Celsius scale,* devised by the Swedish astronomer Celsius, is used by scientists throughout the world. It is abbreviated as C. The value of zero degrees (0°) is assigned to the freezing point of pure water at one atmosphere of pressure. The boiling point of pure water at one atmosphere of pressure is assigned the value of one hundred degrees (100°) on the centigrade scale. Centigrade means 100 degrees.

The Fahrenheit scale has exactly 180 equal divisions or degrees between the freezing point and boiling point of pure water at one atmosphere of pressure. The centigrade scale has exactly 100 equal divisions or degrees between the freezing point and boiling point of pure water at one atmosphere of pressure. Thus, a Fahrenheit degree is 5/9 of a centigrade degree $(\frac{100}{180} = 5/9)$. A centigrade degree is 9/5 of a Fahrenheit degree $(\frac{180}{100} = 9/5)$.

To change temperatures from one scale to another, these formulas can be used:

$$°F = (9/5 \times °C) + 32 \qquad °C = (°F - 32°) \times 5/9$$

Temperatures of interest to astronomers range from about —270°C to 50,000,000°C. Negative numbers, or temperatures expressed in degrees below zero, can be avoided by using the *Kelvin temperature scale.* This is one of many reasons that astronomical publications commonly refer to temperatures in °K. The symbol K is a tribute to Lord Kelvin, an English physicist who made many contributions to the theory and meaning of absolute zero. The Kelvin, or absolute, temperature scale is a Celsius or centigrade scale with zero equal to —273°C. Changing scales from Celsius to Kelvin is a matter of simple addition, as $°K = °C + 273°$.

TABLE B–1. Comparison of Temperature Scales

At one atmosphere of pressure	F	C	K
Freezing point of pure water	32°	0°	273°
Common point	40°	40°	313°
Boiling point of pure water	212°	100°	373°

APPENDIX C
International Atomic Weights

Element	Symbol	Atomic number	Atomic weight	Element	Symbol	Atomic number	Atomic weight
Actinium	Ac	89	227*	Mercury	Hg	80	200.59
Aluminum	Al	13	26.9815	Molybdenum	Mo	42	95.94
Americium	Am	95	243*	Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.183
Argon	Ar	18	39.948	Neptunium	Np	93	237*
Arsenic	As	33	74.9216	Nickel	Ni	28	58.71
Astatine	At	85	210*	Niobium	Nb	41	92.906
Barium	Ba	56	137.34	Nitrogen	N	7	14.0067
Berkelium	Bk	97	247*	Nobelium	No	102	253*
Beryllium	Be	4	9.0122	Osmium	Os	76	190.2
Bismuth	Bi	83	208.980	Oxygen	O	8	15.9994
Boron	B	5	10.811	Palladium	Pd	46	106.4
Bromine	Br	35	79.904	Phosphorus	P	15	30.9738
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.09
Calcium	Ca	20	40.08	Plutonium	Pu	94	244*
Californium	Cf	98	251*	Polonium	Po	84	209*
Carbon	C	6	12.01115	Potassium	K	19	39.102
Cerium	Ce	58	140.12	Praseodymium	Pr	59	140.907
Cesium	Cs	55	132.905	Promethium	Pm	61	145*
Chlorine	Cl	17	35.453	Protactinium	Pa	91	231*
Chromium	Cr	24	51.996	Radium	Ra	88	226.05
Cobalt	Co	27	58.9332	Radon	Rn	86	222*
Copper	Cu	29	63.546	Rhenium	Re	75	186.2
Curium	Cm	96	247*	Rhodium	Rh	45	102.905
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.47
Einsteinium	Es	99	254*	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.35
Europium	Eu	63	151.96	Scandium	Sc	21	44.956
Fermium	Fm	100	253*	Selenium	Se	34	78.96
Fluorine	F	9	18.9984	Silicon	Si	14	28.086
Francium	Fr	87	223*	Silver	Ag	47	107.868
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.9898
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62
Germanium	Ge	32	72.59	Sulfur	S	16	32.064
Gold	Au	79	196.967	Tantalum	Ta	73	180.948
Hafnium	Hf	72	178.49	Technetium	Tc	43	97*
Helium	He	2	4.0026	Tellurium	Te	52	127.60
Holmium	Ho	67	164.930	Terbium	Tb	65	158.924
Hydrogen	H	1	1.00797	Thallium	Tl	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.038
Iodine	I	53	126.9044	Thulium	Tm	69	168.934
Iridium	Ir	77	192.2	Tin	Sn	50	118.69
Iron	Fe	26	55.847	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.91	Uranium	U	92	238.03
Lead	Pb	82	207.19	Vanadium	V	23	50.942
Lawrencium	Lw	103	257*	Xenon	Xe	54	131.30
Lithium	Li	3	6.939	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.97	Yttrium	Y	39	88.905
Magnesium	Mg	12	24.312	Zinc	Zn	30	65.37
Manganese	Mn	25	54.9380	Zirconium	Zr	40	91.22
Mendelevium	Md	101	256*				

*The mass number of the isotope with the longest known half-life.

GLOSSARY

Pronunciation Key

ae . . . bake
ah . . . father
a . . . back
ee . . . easy
e . . . less
eu . . . few
ie . . . life
i . . . trip
oh . . . flow
aw . . . soft
ah . . . odd
oo . . . food
uh . . . foot
eu . . . cube
u . . . up
y . . . yet
j . . . judge
k . . . cake
s . . . sew
th . . . thin

abrade (a braed'): to rub or to wear away by friction

abrasive (a brae' siv): tending to wear away by friction

absolute dates: dates in earth's history arrived at by dating radioactive rocks and measured without reference to any other event

absolute magnitude (mag' na teud): brightness a star would have at a distance of 32.6 light years

absorption lines: dark lines crossing the continuous spectrum of stars showing where frequencies have been absorbed by surface gases

abyss (a bis'): deep part of the ocean floor

acceleration (ik sel a rae' shun): time rate of change of velocity

accessory (ik ses' e ree) **mineral**: mineral present in a minor amount and not necessary to the classification of a rock

aeration (aer ae' shun): exposing to the free action of air; treating of a substance with air

algae (al' jee): plants, such as seaweeds, which grow in water and possess chlorophyll often masked by red or brown pigment

alpha (al' fa) **ray**: stream of positively-charged particles moving at high speed emitted from an atomic nucleus

Alpha Centauri (sen tawr' ee): star, other than the sun, nearest to earth

alluvial (a loo' vee ul): deposits of sand, mud, and other materials transported by flowing water

ammonite (am' a niet): flat, spiral fossil shell of a group of invertebrates abundant in the Mesozoic era

amniotic (am nee aht' ik): having a membrane containing fluid in which the embryo is immersed

amorphous (a mawr' fus): shapeless; having no definite crystal structure

amphibian (am fib' ee an): cold-blooded vertebrate intermediate between fishes and reptiles

amphibole (am' fi bohl): one of the rock-forming mineral groups containing iron, magnesium, calcium, and aluminum silicates in which the silicate tetrahedra are arranged in double chains

amplitude (am' pli teud): vibratory movement of a pendulum as measured from the mean position to the extent of its arc

angiosperm (an' jee a spurm): flowering plant having seeds in a protective covering which enables them to survive and reproduce

angular momentum: momentum of a rotating body as it turns on its axis, governed by mass times velocity times the distance from axis of rotation

anticline (ant' i klien): upward fold or bend of rock strata

anticyclone (ant i sie' klohn): system of wind rotating about a center of high atmospheric pressure, turning clockwise in the northern hemisphere and counterclockwise in the southern hemisphere

aphelion (a feel' yan): point in a planet's orbit farthest from the sun

apogee (ap' a jee): point in the orbit of a satellite of the earth at the greatest distance from the center of the earth

apparent magnitude: brightness of a star observed at its actual distance from earth

aquifer (ak' wa fer): water-bearing rock

arete (a raet'): sharp ridge separating two glaciated valleys

argon (ar' gahn): colorless, odorless, inert gaseous element that composes 0.93 percent (by volume) of the earth's atmosphere

arid (ar' id) **climate**: climate having insufficient rainfall for vegetation

artesian (ahr tee' zhan) **water**: groundwater under enough pressure to rise above the aquifer containing it

asteroid (as' te rawid): fragment of material similar to planetary matter which orbits the sun between Mars and Jupiter

astronomical (as tra nahm' i kal) **unit**: mean distance between the earth and the sun, equal to 93,000,000 mi

atmosphere (at' mu sfir): gaseous mass surrounding the earth or other celestial body

atom (at' em): smallest particle of an element that enters into a chemical reaction

atomic number: total number of protons present in nucleus of atom of a given element

atoll (a′ tawl): ring-shaped coral reef often surrounding a body of water

avalanche (av′ a lanch): large mass of snow, rock, or other material in swift motion down a mountain slope

axis (ak′ sis): imaginary straight line about which a rotating body turns

background noise: unwanted vibrations recorded by a seismograph

bajada (bah hah′ dah): series of alluvial fans which are joined at the foot of a mountain range

barchan (bahr′ kahn): dune with crescent shape when observed from above, having the convex side facing the wind

barometer (ba rahm′ et er): instrument for determining pressure of the atmosphere

baroques (ba rohks′): irregular-shaped polished gems or semiprecious stones

batholith (bath′ a lith): large shield-shaped mass of intrusive igneous rock extending to unknown depths

benthos (ben′ thahs): organisms that live on the bottom of the ocean

bergschrund (burg′ schrund): crevasse at the head of a mountain glacier which separates moving snow and ice from that which clings to the rock face

berm: narrow horizontal portion of a beach built of material deposited by wave action

beta (baet′ a) **ray**: stream of electrons emitted from an atomic nucleus

binary (bie′ na ree) **star**: system of two stars that revolve around each other under their mutual gravitation

boiling point: temperature at which a liquid changes to a gas

brachiopod (brak′ ee a pahd): phylum of marine invertebrates having two unequal shells or valves

buoyancy (bawi′ an see): resultant of upward forces exerted by a fluid on a submerged or floating body, equal to the weight of the fluid displaced by the body

butte (beut): turret-like hills or ridges which rise abruptly from and stand above the surrounding plain

cabochon (kab′ a shahn): gem or bead cut in convex form

caldera (kal der′ a): large basin-shaped depression at the summit of a volcano

caliche (ka lee′ chee): crust of calcium carbonate formed on soil in arid region by evaporation of moisture

Cambrian (kam′ bree an): earliest geologic period of the Paleozoic era; rocks containing fossils of every animal type

canine (kae′ nien): conical pointed tooth suited to tearing flesh

capillary (kap′ e ler ee)**attraction**: rising of liquid in hair-like openings in a solid due to attraction between unlike molecules

carbonate (kahr′ ba naet): compound containing the radical CO_3

carbon dioxide: heavy, colorless gas that composes 0.03 percent (by volume) of the earth's atmosphere

carnivorous (kahr niv′ a rus): flesh-eating

celestial (se les′ chal): pertaining to the sky or visible heavens

celestial sphere: globe with the earth as center on which movements of stars and planets are plotted or mapped

centrifugal (sen trif′ ye gal) **force**: force which tends to impel an object outward from the center of rotation

Cepheid (see′ fee id): pulsating star with regular light variations

chain craters: small pits on the moon's surface aligned in chains

chalcedony (kal sed′ en ee): microscopic fibrous quartz or agate

Chinook (shi nuhk′): evaporating wind that blows downward on the eastern slopes of the Rocky mountains

chromosphere (kroh′ ma sfir): layer of hot gas surrounding the photosphere of the sun

cirque (surk): deep, steep-sided recess or hollow in a mountain caused by glacial erosion

Pronunciation Key

ae . . . bake
ah . . . father
a . . . back
ee . . . easy
e . . . less
eu . . . few
ie . . . life
i . . . trip
oh . . . flow
aw . . . soft
ah . . . odd
oo . . . food
uh . . . foot
eu . . . cube
u . . . up
y . . . yet
j . . . judge
k . . . cake
s . . . sew
th . . . thin

clastic (klas′ tik): rock composed of fragments derived from a pre-existing rock

cleavage (klee′ vij): tendency to split along planes determined by the crystal structure of a mineral

climate (klie′ met): average of local temperature, precipitation, and wind conditions over a period of years

cohesive (koh hee′ siv): tendency of particles of a substance to be bound together as a unit

compaction (kam pak′ shun): decrease in volume of sediments due to pressure of overlying material or drying

compression (kam presh′ un): force or stress that tends to decrease the volume of a substance

compound: two or more elements chemically joined

concave (kahn′ kaev): hollowed or rounded inward like the inside of a bowl

conchoidal (kahn kawid′ l): curved like the inside of a shell

condense (kan dens′): make more dense or compact; to compress the volume of a substance; to change from gas to liquid or solid

conduction (kan duk′ shun): movement of heat, light, electricity, or sound by contact among particles

conglomerate (kan glahm′ e rit): rock consisting of rounded and water-worn pebble-sized fragments cemented by another mineral

consolidate (kan sahl′ i daet): make solid or firm; to unite

constellation (kahn sta lae′ shun): pattern produced by an arrangement of stars and named for some earth object

contact metamorphism: change in rock resulting from contact with hot magma or igneous rock

continental nucleus: region where rocks of the Cryptozoic eon are exposed at the surface

convection (kan vek′ shun): movement of heat and matter (plastic, liquid, or gas) because of differences in density usually resulting from differences in temperature

convex (kan veks′): curved or rounded outward like the outside of a bowl

Coriolis (kohr ee oh′ lis) **force**: apparent force due to the earth's rotation that causes a body in motion to be deflected from its initial path

corona (ka roh′ na): filmy envelope of highly ionized gas beyond the sun's chromosphere

correlate (kawr′ e laet): to match the geologic age or stratigraphic position of one rock body with another

cosmic (kahz′ mik): pertaining to that part of the universe beyond earth's atmosphere

crater (kraet′ er): steep-walled depression at the summit of a volcanic vent

crescent (kres′ ent): figure resembling a bow ending in points; the moon in its first or last quarter when both edges are nearly parallel

crest: highest natural point of a hill, mountain, anticline, or wave

crevasse (kri vas′): fissure or cleft in the ice of a glacier

crosscutting relationships: age relationships of rocks which cut across rocks already in place

crust: crystalline outer layer of the earth

crystal: solid body bounded by plane surfaces showing a regularly repeated arrangement of atoms

crystal faces: flat surfaces of a crystal which join at well-defined angles

cuesta (kwes′ ta): hill or ridge with a steep face on one side and a gentle slope on the other

cyclone (sie′ klohn): system of wind rotating about a center of low atmospheric pressure, turning clockwise in the southern hemisphere and counterclockwise in the northern hemisphere

daughter element: element formed from another by radioactive decay

debris (da bree′): loose material resulting from decay and disintegration

declination (dek le nae′ shun): distance north or south from the celestial equator, measured along a great circle passing through the celestial poles; celestial coordinates corresponding to latitude on earth

Pronunciation Key

ae . . . bake
ah . . . father
a . . . back
ee . . . easy
e . . . less
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ie . . . life
i . . . trip
oh . . . flow
aw . . . soft
ah . . . odd
oo . . . food
uh . . . foot
eu . . . cube
u . . . up
y . . . yet
j . . . judge
k . . . cake
s . . . sew
th . . . thin

decomposition (dee kahm pa zish′ un): chemical separation of minerals and rocks into elements or simpler compounds

deflation (di flae′ shun): removal by wind of loose material from the land surface

deflection (di flek′ shun): act of bending or turning aside

delta: triangular-shaped alluvial deposit at the mouth of a river

dendritic (den drit′ ik): branching figure resembling a tree

density (den′ sit ee): mass per unit volume

density current: ocean current caused by differences in density due to unequal amounts of suspended or dissolved substances in water or due to differences in temperatures

deposition (dep u zish′ un): laying down of possible rock-forming sediments; precipitation of dissolved substances

detritus (di triet′ us): loose material resulting from rock disintegration

diastrophism (die as′ tra fiz em): process by which the crust of the earth is deformed causing continents, ocean basins, plateaus, mountains, folds, and faults

diatom (die′ a tahm): small one-celled algae which secrete siliceous material

dike: tabular body of igneous rock that cuts across another rock body

dinosaur (die′ na sawr): group of large extinct reptiles

dipole (die′ pohl): directional antenna for collecting radio waves

disintegration (dis int e grae′ shun): mechanical breaking of material into small particles during weathering

displacement: relative movement of two sides of a fault measured in any specified direction

dissect (dis ekt′): to cut into hills and valleys during erosion of a plateau or uplifted peneplain

doldrums (dohl′ drumz): calm, windless area near the equator

dominant (dahm′ a nant): controlling or most influential

Doppler (dahp′ ler) **effect**: change in the frequency with which waves from a given source reach the observer when the source and the observer are in rapid motion with respect to one another

drumlin: long, narrow, smoothly rounded hill of unstratified glacial drift

dynamic (die nam′ ik) **metamorphism**: metamorphism resulting from rock folding or faulting

eccentric (ik sen′ trik): not following a circular path; deviating from an established pattern

eclipse (i klips′): passing of a luminous body into the shadow of another body

eclipsing variables: two stars that orbit around a common point and appear to change magnitude because one of them is dimmer

ecliptic (i klip′ tik): great circle inclined to the celestial equator at an angle of 23° 27′ formed by the intersection of the plane of the earth's orbit with the celestial sphere

eddy: current of water, air, or gas running contrary to the main current

electron (i lek′ trahn): nearly weightless subatomic particle with a negative electrical charge

electron cloud: portion of an atom consisting of negative electricity surrounding the nucleus

element: any substance which, in its pure form, cannot be separated into simpler substances

ellipse (i lips′): curved plane surface generated by a point that moves so the sum of its distance from two fixed points is constant

embryo (em′ bree oh): organism in the early stages of development

energy level: one of a series of levels in which electrons vibrate around the nucleus of an atom

entrench: to erode downward so as to form a trench beneath the general surface of the adjacent upland

environment (in vie′ ran ment): sum total of all external conditions surrounding an organism or community

Pronunciation Key

ae . . . bake
ah . . . father
a . . . back
ee . . . easy
e . . . less
eu . . . few
ie . . . life
i . . . trip
oh . . . flow
aw . . . soft
ah . . . odd
oo . . . food
uh . . . foot
eu . . . cube
u . . . up
y . . . yet
j . . . judge
k . . . cake
s . . . sew
th . . . thin

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eolian (ee oh′ lee an): borne, deposited, or eroded by wind

eon (ee′ an): one of the two largest divisions of geologic time

epicenter (ep′ i sent er): point on the earth's surface directly above the focus of an earthquake

epoch: subdivision of a period in geologic time

equilibrium (ee kwa lib′ ree um): state of balance between opposing forces

equinox (ee′ kwa nahks): position where the center of the sun crosses the plane of the earth's equator making day and night of equal length

era (ir′ a): large division of geologic time containing more than one period

erosion (i roh′ shun): process by which materials of the earth's surface are loosened or dissolved and removed

erupt (i rupt′): to burst forth, as the violent outpouring of lava from a volcano

escarpment (is kahrp′ ment): a steep slope separating two gently sloping surfaces

esker: a serpentine ridge or hill of sand or gravel deposited within stream channels in a decaying glacier ice sheet

essential mineral: mineral necessary to the classification of a rock

estuary (es′ cha wer ee): bay at the lower end of a river where the river current meets the tide

etch: to pit or corrode a mineral or rock surface so as to produce a pattern of pits or lines

evaporation (i vap e rae′ shun): physical change from liquid to gas; process by which water becomes a vapor at a temperature below the boiling point

evaporite (i vap′ e riet): product of evaporation; sediment left after evaporation of a solvent

exfoliation (eks foh lee ae′ shun): the peeling off of thin, concentric layers from a bare rock surface

exosphere: outer layer of earth's atmosphere which contains helium, hydrogen, radioactive particles, and bands of radiation

extinct (ik stingkt′): no longer existing

extrusive (ik stroo′ siv): igneous rocks which have been consolidated at or near the earth's surface

faceted (fas′ et ed): polished with small, plane surfaces meeting at sharp angles

facies (fae′ shee eez): areally differing characteristics (composition, fossil content, or texture) of a geologic unit of deposition

fault: fracture of the earth's crust along which displacement of one side of the fracture with respect to the other has occurred

firn: compact, permeable mass of granular snow which has remained for more than one season and forms the upper surface of the accumulation area of a glacier

fluvial (fleu′ vee al): produced by stream action

focal length: distance between the focal point and the lens

focal point: point at which light rays converge to form a small image on a lens

focus: true center of an earthquake

fold: bend in rock strata

foliation (foh lee ae′ shun): structure in certain metamorphic rocks resulting from segregation of different minerals into parallel layers

fossil (fahs′ il): record of past life, such as a shell, bone, or impression, preserved in the earth's crust

fossil assemblage: fossils naturally associated in a stratum and possibly derived from more than one fossil community

fossiliferous (fahs i lif′ e ras): containing organic remains

fracture (frak′ chur): distinctive manner of breaking in a mineral other than along a plane surface; breaks in rocks due to intense folding and faulting

freezing point: temperature at which a liquid becomes a solid

frequency (free′ kwan see): number of repetitions of a periodic wave per unit of time

fretwork: pattern of dark and light; a design worked by perforations

fuse: to combine or blend by melting together

galaxy (gal′ ak see): system or community of stars

gamma ray: most penetrating and destructive atomic ray emitted by radioactive substances

gangue (gang): worthless rock surrounding valuable minerals

gas: form of matter without definite shape or volume

gem: precious or semiprecious stone which may be polished for ornament

geode (jee′ ohd): hollow, globular body of rock often lined with inward growing mineral crystals

geodesists (jee ahd′ e sists): scientists who measure earth's shape, size, gravity, and magnetism

geodetic (jee a det′ ik) **surveys:** mathematical measurements of earth's dimensions

geologic revolution: time of major crustal deformations

geosyncline (jee oh sin′ klien): great regional, subsiding, downward warp of the earth's crust in which thousands of feet of sediment and volcanic rock accumulate

geyser (gie′ zer): spring that irregularly throws forth jets of hot water and steam

gibbous (gib′ us): moon when more than half but not all its disc is illuminated

globule (glahb′ eul): small, spherical body

gorge (gawrj): narrow, deep passage between rocky sides

gradient (graed′ ee ent): slope, particularly of a stream or land surface

granule (gran′ eul): rounded rock fragment larger than sand grains but smaller than pebbles

gravitation (grav i tae′ shun): mutual attraction between all matter

gravity (grav′ it ee): gravitational attraction of the earth for objects near its surface

gully (gul′ ee): trench worn by running water

half-life: time in which half the initial number of atoms of a radioactive element disintegrate into atoms of a daughter element

hardness: resistance to scratching or abrasion

helium (hee′ lee um): light, colorless gaseous element usually containing 2 protons, 2 neutrons, and 2 electrons

herbivorous (er biv′ a rus): plant-eating

hexagonal (hek sag′ an l): crystal system having three equal lateral axes intersecting at angles of 60° in one plane and a fourth unequal axis perpendicular to the others

hogback: ridge produced by sharply tilted resistant strata left exposed as adjacent weaker strata are eroded into deep ravines

horizontal seismograph: instrument used to record horizontal vibrations of earth

humic (heu′ mik) **acid:** product of decomposition of plant or animal matter

hydraulic (hie draw′ lik): operated or moved by means of water in motion

hydrocarbon (hie dra kahr′ bon): organic compound of carbon and hydrogen

hydrogen (hie′ dra jen): light, colorless gaseous element usually containing 1 proton, 1 electron, and no neutrons

hydrologic (hie dra lahj′ ik) **cycle:** cycle of water circulation from sea to atmosphere, to land, to sea again

hydrosphere (hie′ dru sfir): water portion of the earth including water vapor in air, seas, rivers, and groundwater

hypothesis (hie pahth′ e sis): proposition or an assumption based on available information offered as an explanation for a problem

igneous (ig′ nee us): rock formed by solidification of molten material produced under conditions of intense heat

impression: form or shape left on a soft surface by material which has come in contact with it; preserved form of a fossil

incisor (in sie′ zer): tooth adapted for cutting

index fossil: fossil with a narrow time range and wide distribution used to identify and date the rock layer in which it occurs

industrial mineral: nonmetallic mineral important in industry

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eu . . . cube
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inertia (in er′ shuh): resistance to motion or to change of direction

inorganic: not having the characteristics of living things; not capable of self-duplication or producing offspring

inselberg (in′ sel burg): bare, rocky, steep-sided residual hills rising from eroded plains

intact: unaltered, sound, or whole

interferometer (int er fa rahm′ et er): multiple-element antenna feeding a single receiver to aid in distinguishing between sources of radiation

intermittent (int er mit′ ent): alternately ceasing and beginning again

international date line: imaginary line at approximately the 180° meridian at which the date is adjusted, being one day later west of the line than east of it

intersect (int er sekt′): to pierce or divide by passing through or across

intrusive (in troo′ siv): rock which, while fluid, has penetrated into or between other rocks, but has solidified before reaching the surface of the earth

invertebrate (in vert′ e brat): animal lacking a spinal column

ion (ie′ an): electrically charged atom

ionosphere (ie ahn′ a sfir): layer of the earth's atmosphere about 50 mi to 600 mi above earth's surface containing free electrically charged particles by means of which radio waves are transmitted to distant areas

isostasy (ie sahs′ ta see): condition of equilibrium in the earth's crust in which masses of greatest density are lower than those of lesser density

isotopes (ie′ sa tohps): atoms of the same element having different mass because of differences in the number of neutrons

jetty (jet′ ee): projection built into a body of water to influence current or tide

kame: conical, irregular hill of sand or gravel deposited at the edge of a glacier ice sheet

laccolith (lack′ a lith): mushroom-shaped body of intrusive igneous rock which has domed up the overlying rock and has a floor that is usually horizontal in contrast to the larger batholith

lagoon (la goon′): area of shallow salt water possessing a restricted connection with the sea

larvae (lahr′ vee): early forms of any animal which is unlike its parents and must change before adulthood

lateral (lat′ e ral) **moraine**: body of unstratified drift or till lying on the surface near and parallel to the sides of a valley glacier

latitude (lat′ i teud): distance north or south of the earth's equator measured in degrees

lava (lahv′ a): fluid rock issuing from a volcano or fissure, or same material cooled and solidified

leeward: direction toward which the wind is blowing

legumes (le′ geums): plants whose nitrogen-fixing bacteria form usable nitrogen compounds

levee (lev′ ee): man-made or natural bank confining a stream channel

light year: distance that light travels in one year, equal to 6×10^{12} mi/yr

linear (lin′ ee ar): involving a single dimension; straight

liquid: form of matter without definite shape but having definite volume

lithium (lith′ ee em): soft, silver-white element; lightest known metal

lithology (lith ahl′ a jee): study of rocks

lithosphere (lith′ a sfir): solid outermost part of the earth; the earth's crust

loess (les): nonstratified silt and clay deposited by wind

longitude (lahn′ ji teud): distance east or west of the prime meridian at Greenwich, England, measured in degrees

longitudinai (lahn ji teud′ nal): of or relating to lengthwise dimension

longshore current: local current flowing parallel to the shore caused by waves breaking at an angle to the shore

luminous (loo′ ma nus): emitting light

luminosity (loo ma nahs′ at ee): quality of giving off light

luster: character of light reflected by a mineral

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Magellanic (maj e lan′ ik) **Clouds**: two galaxies nearest the Milky Way and appearing as conspicuous patches of light

magma (mag′ ma): molten rock material which is formed beneath the earth's crust and from which igneous rocks are solidified

main sequence stars: normal stars or stars in equilibrium

malleable (mal′ ee a bul): capable of being shaped by pounding

mammal (mam′ el): any of a class of higher vertebrates that nourish their young with milk secreted from glands

mantle (mant′ ul): layer of the earth between the crust and the core

maria (mae′ ree a): depressions on the moon's surface once believed to be seas

marsupial (mahr seu′ pee al): lower mammal groups that have a pouch on the female in which the young are carried

mass: measure of the quantity of matter in a body

mass number: total number of protons and neutrons present in the nucleus of each atom of a given element

matter: anything that has mass and occupies space

meander (mee an′ der): turn or loop-like bend in a stream channel

melting point: temperature at which a solid becomes a liquid

meltwater: water from the melting of ice or snow

meridian (ma rid′ ee an): great circle on the surface of the earth passing through the poles and crossing the equator at a right angle

mesa (mae′ sa): isolated hill having steeply sloping sides and a level top protected by a resistant layer of rock

mesosphere (mez′ a sfir): layer of earth's atmosphere about 20 mi to about 50 mi above earth's surface containing ozone which absorbs ultraviolet rays

metal: opaque, fusible, ductile, lustrous element

metamorphic (met e mawr′ fik): rock changed in composition or texture after consolidation as a result of deformation and/or increased temperature

metasomatism (met a soh′ ma tiz um): metamorphic changes in chemical composition and texture by introduction of new material into a mineral or group of minerals

meteoroid (meet′ ee a rawid): fragment of cosmic material too small to be observed from earth

meteorology (meet ee a rahl′ a jee): science dealing with the atmosphere and its phenomena, particularly relating to weather

mid-oceanic ridge: mountain ridge in mid-ocean which extends for about 40,000 mi roughly parallel to continental margins

migmatites (mig′ ma tiets): rocks containing alternate layers of igneous and metamorphic rocks

migrating dune: dune which moves more or less as a unit because of wind action

mineral: inorganic substance which occurs in nature, in the solid state, with a definite chemical composition and characteristic internal atomic pattern

mineraloid (min′ ra lawid): similar to a mineral except that it has no characteristic internal pattern

mixture: two or more substances combined in any proportion which, unlike a chemical compound, retain their identity and can be separated by mechanical means

Mohorovicic discontinuity (moh ha roh′ va chich · dis kahnt en eu′ et ee): position within the earth at which seismograph study indicates an abrupt change in density; boundary between the solid crust and the plastic mantle; often referred to as Moho

molar (moh′ lar): tooth with a flat surface suited to grinding

molecule (mahl′ i keul): smallest particle of a substance that can exist separately and retain its distinct characteristics

mollusk (mahl′ usk): phylum of invertebrate animals enclosed in a symmetrical calcareous shell

molten (mohlt′ en): liquified by heat

monadnock (ma nad′ nahk): residual rock, hill, or mountain standing on an eroded plain

monocline (mahn′ a klien): change in dip from horizontal strata downward and back to horizontal

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i . . . trip
oh . . . flow
aw . . . soft
ah . . . odd
oo . . . food
uh . . . foot
eu . . . cube
u . . . up
y . . . yet
j . . . judge
k . . . cake
s . . . sew
th . . . thin

monsoon (mahn soon′): wind which reverses with the seasons; wind established between water and adjoining land

moon phase: apparent change in the shape of the moon's disc because of the moon's revolution around the earth and change in its reflected light from the sun

moraine (ma raen′): deposit of unstratified gravel, sand, clay, and boulders left by direct melting of a glacier

mutation (meu tae′ shun): sudden fundamental change in heredity producing new individuals unlike the parents

myth: imaginative story used to explain a natural phenomenon

native metal: metal found in an uncombined state in nature

neap tide: tide of minimum range occurring at the first and third quarters of the moon

nebula (neb′ ye la): immense body of highly rarefied gas and dust in interstellar space

nebular (neb′ ye ler) **hypothesis**: proposition which states that the solar system evolved from hot gaseous nebulae

nekton (nek′ tan): free-swimming marine organisms

neutron (neu′ trahn): particle in the nucleus of an atom that has no electrical charge

neve (nae vae′): permeable mass of snow granules forming the upper surface of the accumulation area of a glacier

nitrogen (nie′ tra jen): colorless, tasteless, gaseous element constituting 78 percent (by volume) of the earth's atmosphere

nodule (nahj′ ool): rounded body of irregular shape formed within certain sedimentary layers of rock

nonmetal: element that lacks metallic properties

notched cliff: cliff with indentation cut by wave action

nova (noh′ va): star that irregularly, yet suddenly, increases its light output tremendously and then fades to its former obscurity as it loses mass

nucleus (neu′ klee us): central point or portion of an atom around which electrons are gathered; central portion of a galaxy

nutation (neu tae′ shun): periodic oscillation or nodding of the earth's axis

nutrient (neu′ tree ent): substance that promotes growth

oasis (oh ae′ sis): fertile green spot in a waste or desert

objective lens: lens of a telescope which is exposed to the object under observation and which produces an image of the object for viewing with the eyepiece

oblate spheroid (ahb′ laet · sfir′ awid): spherical body that bulges at its equator and is flattened at its poles

octahedron (ahk ta hee′ dron): solid bounded by eight plane faces

ocular (ahk′ ye lar) **lens**: lens of a telescope which is the eyepiece for magnifying

ooze: fine-grained mud of more than 30 percent organic origin which covers parts of the ocean floor

opaque (oh paek′): not capable of transmitting light or radiant energy

orbit (awr′ bit): path of a body in its revolution around another body

ore: mineral or groups of minerals which can be mined at a profit

orthoclase (awr′ tha klaes): potassium—containing mineral member of the feldspar family; most abundant mineral in granites

orthorhombic (awr tha rahm′ bik): crystal system having three unequal axes intersecting at right angles

oscillatory (ah sil′ a tohr ee) **wave**: wave in which particles move about a point with little permanent change in position; a deep water wave

oxide: chemical compound containing oxygen combined with a positive ion or ions

oxygen: colorless, tasteless, odorless gaseous element constituting 21 percent (by volume) of the earth's atmosphere

ozone (oh′ zohn): form of oxygen having three atoms to the molecule

Pronunciation Key

ae ... bake
ah ... father
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ee ... easy
e ... less
eu ... few
ie ... life
i ... trip
oh ... flow
aw ... soft
ah ... odd
oo ... food
uh ... foot
eu ... cube
u ... up
y ... yet
j ... judge
k ... cake
s ... sew
th ... thin

paleontologist (pae lee ahn tahl′ a jist): scientist who studies the life of past geologic ages through fossils

parabolic (par a bahl′ ik) **dune**: curved dune with the concave side toward the wind

parsec: unit of measure for interstellar space, equal to 3.26 light years

peat: partially carbonized vegetable tissue

pendant (pen′ dant): small solutional remnant projecting from the ceiling

pendulum (pen′ je lum): body suspended from a fixed point so as to swing back and forth in response to the action of gravity and momentum

perceptible (per sep′ ta bal): capable of being recognized or seen

percolating (per′ ka laet ing): oozing or trickling through fine openings in a permeable substance

periodotite (pa rid′ a tiet): igneous rocks composed of olivine and another ferro-magnesian mineral, usually a pyroxene

perigee (per′ a jee): point in the orbit of a satellite of the earth at the least distance from the center of the earth

perihelion (per i heel′ yan): point in a planet's orbit nearest the sun

perimeter (pa rim′ et er): outer boundary of a two-dimensional figure; the circumference

period: fundamental unit of the geologic time scale; time required for a complete swing of a pendulum from maximum position to minimum position

periphery (pa rif′ a ree): external surface or boundary of an area

permeable (pur′ mee a bul): having a texture that permits liquid to move through the pores

permineralize: fossilization whereby original hard parts of an organism have additional mineral material deposited in their pores

petrify (pe′ tra fie): to change into stone or a stony substance

petroleum (pe troh′ lee am): liquid, flammable hydrocarbon

phenomenon (fi nahm′ e nahn): fact, occurrence, or circumstance observed

philosophy (fi lahs′ a fee): study or science of the principles of a particular branch of knowledge

photometer (foh tahm′ et er): instrument for measuring intensity of light energy

photosphere (foht′ a sfir): luminous, visible part of the sun

photosynthesis (foht a sin′ tha sis): formation of carbohydrates from carbon dioxide in the tissues of plants exposed to sunlight

phylum (fie′ lem): primary division of a kingdom

physics (fiz′ iks): science dealing with natural laws and physical changes of matter

piedmont (peed′ mahnt): area lying along or near the foot of a mountain range

placer (plas′ er): alluvial deposit, as of sand or gravel, containing gold or other valuable minerals

plagioclase (plae′ jee a klaes): mineral group belonging to the feldspar family containing sodium silicate and/or calcium silicate

plane: flat or level surface

planetesimal (plan e tes′ i mal): small, solid body in space revolving around a larger body

plankton (plangk′ tan): marine organisms that float at or near the ocean surface

plateau (pla toh′): level land area rising above adjacent land

playa (plie′ a): desert basin without drainage where water collects and evaporates

pluvial (ploo′ vee al): characterized by abundant rain

porous: having openings which may or may not be connected

porphyry (pawr′ fa ree): rock with distinct crystals in a fine-grained ground mass

precession (pree sesh′ un): cone-shaped motion traced by the axis of a rotating body acted on by an outside force that tilts the axis away from the perpendicular to the plane of its orbit

precious stone: gem of great commercial value because of its rarity, beauty, and durability

precipitation (pri sip i tae′ shan): discharge of water in liquid or solid state from the atmosphere; process of separating minerals from a solution or melt by chemical reaction or evaporation

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prevailing (pri vael′ ing): having superior power or influence

primary wave: earthquake wave which vibrates back and forth in direction of wave travel

prime meridian: meridian which passes through Greenwich, England, and from which distances east and west on the earth's surface are measured

prism (priz′ em): transparent body having three or more similar plane faces which are parallel to a common axis and used to disperse a beam of light

protista: group of one-celled microscopic organisms having characteristics of either plants or animals

proton (proh′ tahn): particle in the nucleus of an atom having a positive electrical charge; a unit of positive electricity

protoplanet: first form of a planet

pyroxene (pie rahk′ seen): one of the rock-forming mineral groups containing iron, magnesium, calcium, sodium, and aluminum silicates in which the silicate tetrahedra are arranged in a single chain

quadrant (kwahd′ rant): instrument for measuring altitudes consisting of a graduated arc of 90° with a plumb line for fixing the vertical direction

quasar (kwae′ zar): from *quas*i stell*ar*; source of radio energy from outer space, not stars; celestial objects possessing certain attributes of stars, but which are not stars

radar (rae′ dahr): from *ra*dio *d*etecting *a*nd *r*anging; instrument for detecting a target and measuring the travel time of a radio pulse sent out from a transmitter and reflected by the target in order to determine the distance and direction of the target

radiation (raed ee ae′ shun): process of emitting radiant energy in the form of waves or particles

radioactive decay: changing one element into another element through loss of charged particles from the atomic nucleus without the influence of heat, pressure, or chemical reaction

radioactive element: element capable of changing spontaneously into another element by emission of charged particles from the nucleus of its atoms

radiometer (raed ee ahm′ et er): instrument for measuring the intensity of radiant energy

rank: measure of intensity of metamorphism

rays: bright streaks radiating from some moon craters

recede (ri seed′): withdraw or move back

recrystallization: formation of new mineral grains or enlargement of pre-existing mineral grains caused by thermal metamorphism

red shift: shift of all spectral lines in light from receding distant galaxies toward longer wavelengths or the red end of spectrum characteristic of all galaxies

reflecting telescope: telescope in which incoming light is converged into an image by a concave mirror rather than a lens

refract (ri frakt′): to bend or deflect from a straight line

refracting telescope: telescope using an objective lens to produce an image of the object under observation and an ocular lens through which the observer views the image

regional metamorphism: large scale metamorphism that affects an entire region, but need not be related to known igneous intrusions

rejuvenation (ri joo va nae′ shun): to restore to a youthful state

relative dates: dates in earth's history determined with reference to other events

relief (ri leef′): difference between high and low elevations of a land surface

reptile (rep′tel): cold-blooded vertebrate that moves on its underside or on short legs

reservoir (rez′ urv wahr): artificial lake where water is stored for use; a natural underground container of oil, water, or gas

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residual (ri zidj′ wal): that which remains in the place it was formed

resistant (ri zis′ tent): that which withstands or opposes force

retrograde: having direction contrary to general direction of similar bodies

revolution (rev a loo′ shun): moving of a body in a circular course about a central point; a time of major crustal deformations

rhombohedron (rahm boh hee′ dron): solid with faces that are parallelograms with oblique angles

right ascension (a sen′ chun): distance eastward from the point where the celestial equator and the ecliptic intersect on the spring equinox; celestial coordinate which corresponds to longitude on earth

rills: long, narrow markings on the moon's surface having steep sides, flat bottoms, and varying widths; minute stream channels on earth

rip current: seaward-moving current that returns water from the shore to greater depths

rotation (roh tae′ shun): turning motion of a body on its axis

satellite (sat′ el iet): body revolving about a larger body

saturate (sach′ u raet): to soak thoroughly so that all openings are filled with fluid

saturation (sach u rae′ shun): degree to which rock openings are filled with fluid or a solution contains all the dissolved material possible at a given temperature

scavenger (skav′ en jer): organism that feeds on refuse or decaying flesh

scientific theory: general principle offered to explain observed facts and events

secondary crater: small crater near large crater on the moon's surface

secondary wave: earthquake wave which moves up and down perpendicular to direction of wave travel

sedimentary (sed a ment′ a ree): rock formed of sediments—either fragments of other rock deposited by wind or water or material precipitated from solutions

seismic (sies′ mik): characteristic of or produced by earth vibrations

seismograph (siez′ ma graf): instrument to record vibrations of the earth

semiprecious stone: gem of less commercial value than a precious stone

shadow zone: area between 103° and 143° on either side of earthquake focus where no *P* or *S* waves are recorded

shearing: stress resulting from applied forces that cause two adjacent parts of a solid to slide past one another parallel to the plane of contact

shield: continental block of the earth's crust that has been relatively stable since Precambrian time; a disc-shaped volcano

shoreline: average position of line where land and sea meet

sidereal (sie dir′ ee al): pertaining to measurements determined by positions of stars

siderite (sid′ a riet): meteorite of iron or iron and nickel

siderolite (sid′ e ra liet): sponge-like iron meteorite with stony material in its pores

silicate (sil′ i kaet): chemical compound which is a combination of silicon, oxygen, and some other element or elements

sill: tabular igneous rock body intruded between and also parallel to older rock layers

slip face: leeward slope of sand dune down which sand slides because of gravity

slit: narrow opening designed to let a minimum beam of light reach the spectroscope

solid: state of matter which has a definite shape and volume because molecules cannot move freely from place to place

solstice (sahl′ stis): point in the ecliptic at which the sun is farthest either north or south from the equator

solution (sa loo′ shun): condition in which particles of a solid are dissolved in a liquid and cannot be separated by filtration

species (spee′ sheez): class of individuals having common characteristics and capable of interbreeding

Pronunciation Key

ae . . . bake
ah . . . father
a . . . back
ee . . . easy
e . . . less
eu . . . few
ie . . . life
i . . . trip
oh . . . flow
aw . . . soft
ah . . . odd
oo . . . food
uh . . . foot
eu . . . cube
u . . . up
y . . . yet
j . . . judge
k . . . cake
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specific (spi sif′ ik) **gravity**: ratio of the mass of a body to the mass of an equal volume of water

spectrogram (spek′ tra gram): photograph of a spectrum

spectrograph (spek′ tra graf): apparatus for dispersing radiation into a spectrum and photographing the spectrum

spectroheliograph (spek troh hee′ lee a graf): apparatus for photographing the sun in the light of a single wavelength

spectroscope (spek′ tra skohp): instrument for examining the visible spectrum

spectrum: band of visible colors formed when a beam of radiant energy is dispersed and its rays are arranged in the order of their wavelength or frequency

spheroidal (sfir awid′ al): having a shape resembling a sphere

spiral: winding around a center and gradually receding from it

spontaneous (spahn tae′ nee us): produced by natural causes

spring tide: high tide caused by position of sun, earth, and moon in a straight line

stable (stae′ bel): able to continue or last; not changeable

stack: vertical block of resistant rock cut off from the mainland by wave action

stadium (staed′ ee um): ancient measure of distance

stalactite (sta lak′ tiet): deposit of calcium carbonate hanging from the roof or sides of a cavern

stalagmite (sta lag′ miet): deposit of calcium carbonate built up from the floor of a cavern by the drip of water from above

stoping (stohp′ ing): process in which magma engulfs blocks of overlying country rock and assimilates them

strata (strae′ ta): layers of the same kind of rock material, usually applied to sedimentary rock layers

stratigraphy (stra tig′ ra fee): science that deals with origin, composition, distribution, and succession of rock strata

stratosphere (strat′ a sfir): layer of earth's atmosphere from about 7 mi to about 20 mi above earth's surface having relatively constant temperature and little water content

streak: color of the fine powder of a mineral obtained by scratching it against a hard white surface

stress: amount of physical pressure, pull, or other force exerted per unit of area

striation (strie′ ae shun): one of a group of parallel grooves caused by abrasion by ice or rock

striated (strie′ aet ed): marked with usually parallel grooves or channels

stylus (stie′ lus): hard-pointed, pen-shaped instrument for marking

subatomic particle: component of an atom too small to be seen with any instrument

subsidence (sub sied′ ens): act of sinking or settling

substance: matter including both elements and compounds

summit: highest point or part of a hill or mountain

superficial (seu per fish′ al): of or relating to or affecting only the surface

superposition: order in which rocks are deposited one above the other

suspension: state in which particles of a solid are mixed with a fluid but are undissolved

symmetrical (sa me′ tri kal): having parts that correspond in size, shape, and relative position on opposite sides of a dividing line or axis

syncline (sin′ klien): fold in rock in which strata dip inward from both sides

synodic (sa nahd′ ik): interval of time required for a celestial body to complete one revolution as seen from the earth

talus (tae′ lus): heap of rock debris at the base of a cliff

tangent (tan′ jent): touching

tension (ten′ chun): system of forces tending to pull a body apart; the stress resulting from such forces

terminal (term′ nal) **moraine**: moraine situated at or forming the end of a glacier

terrace (ter′ as): level surface bounded by a steep ascending slope on one side and a steep descending slope on the other

terrestrial (te res′ tree al): consisting of or representing the earth

tetragonal (te trag′ an l): crystal system having three axes at right angles to one another, two being of equal length and one longer or shorter

tetrahedron (te tra hee′ dron): a solid bounded by four plane faces

texture (teks′ cher): characteristics of rock particles including size, shape, and arrangement of the particles

thermal (ther′ mal): of or pertaining to heat

tidal: of or pertaining to the periodic rise and fall of waters of the ocean

tidal scour: channels eroded by movement of tidal waters

time-path: shortest time from instant earthquake wave is initiated until it is received by a seismograph, governed by different wave velocities of earth material, but not always the shortest distance

topography (ta pahg′ ra fee): surface features of an area

torrential (taw ren′ chal): violent, having the nature of a torrent

transmutation (trans meu tae′ shan): transformation of one element into another through nuclear reactions

transpiration (trans pa rae′ shun): process by which water vapor escapes from a living plant into the atmosphere

transverse (trans vers′) **dune**: dune lying across or at right angles to the wind

travertine (trav′ er teen): mineral composed of calcium carbonate deposited by a hot spring

tremor (trem′ er): vibratory movement; a quivering or trembling

tributary (trib′ ye ter ee): stream contributing water to another larger stream

trilobite (trie′ la biet) **hash**: undistinguishable mixture of broken segments of fossil trilobites

tropics: zone of the earth's surface extending 23½° north and 23½° south on either side of the equator

troposphere (troh′ pa sfir): layer of the earth's atmosphere from the surface to about 7 mi above the earth containing about 75 percent of the gases of the atmosphere

tsunami (seu nahm′ ee): great sea wave produced by a submarine earthquake

turbidity (tur bid′ it ee) **current**: ocean current caused by density of water containing sediment in suspension

turbulence (tur′ beu lans): haphazard, secondary motion caused by eddies in a moving fluid or air current

unconformity: break in the rock record

undulate (un′ ja laet): to move in rising and falling flowing waves

uniformitarianism (eu ni fawr mi ter′ ee a niz em): geological principle that states that processes of the present are similar to processes of the past

uranium (eu rae′ nee am): heavy, radioactive, metallic element found in pitchblende existing naturally as a mixture of three isotopes

variance (ver′ ee ans): disagreement between two parts

vein: narrow, well-defined zone containing mineral-bearing rock in place

velocity (ve lahs′ et ee): time rate of linear motion in a given direction

veneer (va nir′): overlay of thin sheets of some material

vertical seismograph: instrument used to record vibrations at right angles or up and down during an earthquake

vesicular (va sik′ ya ler): containing many small cavities due to the escape of gas or vapor

vibration: quiver or tremor; an oscillation

viscous (vis′ kus): pertaining to a fluid which resists flowing because of the cohesion of its molecules

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wavelength: horizontal distance between similar points on two successive waves measured perpendicularly to the crest

weather: day-to-day changes in wind, temperature, humidity, and pressure

weathering: physical disintegration and chemical decomposition of earth material at or near the surface

weight: measure of gravitational pull of the earth on bodies near the surface of the earth

windward: direction from which the wind is blowing

wrinkle ridges: raised ridges on the surface of the moon probably caused by compression

zenith (zee′ neth): point on the celestial sphere directly above the observer; highest point reached in the heavens by a celestial body

zodiac: imaginary belt about 18° wide with the ecliptic in the center and containing the apparent path of the principal planets except Pluto

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